AN EVALUATION OF SMARTPHONE DRIVER SUPPORT SYSTEMS FOR
YOUNG DRIVERS - ACCEPTANCE, EFFICACY,
AND DRIVER DISTRACTION.

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requirements for the Degree of Doctor of Philosophy (Psychology)

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‘But I at last with weary feet
Will turn towards the lighted inn,
My evening-rest and sleep to meet.’

J. R. R. Tolkien.

‘All was well.’

J. K. Rowling.
List of Works

Below is a list of publications and conference presentations, which have stemmed from work relating to this thesis.

Publications


Conference Presentations


Awards

May 2014: Awarded a College of Arts, Social Sciences and Celtic Studies Travel Bursary by the National University of Ireland, Galway to attend and present at the 28th International Congress of Applied Psychology in Paris, July, 2014.

May 2013: Awarded a College of Arts, Social Sciences and Celtic Studies Travel Bursary by the National University of Ireland, Galway to attend and present at the 27th conference of the European Health Psychology Society in Bordeaux, July, 2013.
Abstract

Background: Smartphone Driver Support Systems (SDSSs) are novel smartphone applications designed to monitor, give feedback on, and improve driving behaviours. Young drivers (aged 18-24) are a priority market for SDSS providers as they are disproportionately represented in the Road Traffic Collision (RTC) fatality and injury statistics. Although studies examining the use of conceptually similar In-Vehicle Data Recorders (IVDRs) would support the assertion that SDSSs will have a similar road safety value, no empirical research has tested this to date.

Aims: The primary aims of the current programme of research were to: a) investigate young driver acceptance of these new systems; b) determine if they can be effective in improving young driver behaviour; and, c) explore whether or not they may distract young drivers and present a RTC risk.

Methodology: These aims were addressed over a series of studies that converge around three research themes: ‘technology acceptance’, ‘efficacy in improving driver behaviour’, and ‘potential for distraction’. Acceptance studies consisted of a systematic review of research examining the acceptability of in-vehicle monitoring for young drivers (Study 1, \( k = 6 \)), and the testing of a novel model to elucidate the factors influencing young driver acceptance of SDSS technology (Study 2, \( n = 333 \)). The efficacy studies commenced with a systematic review of research that tested the impact of monitoring on the driving performance of young people (Study 3, \( k = 8 \)). As the experimental studies in this programme of research utilised a novel driving simulator, a simulator adaptation (Study 4a, \( n = 30 \)) and validation study (Study 4b, \( n = 30 \)) were also conducted at this stage. These were followed by an examination of the impact of driving with a monitoring SDSS on young driver speed (Study 5, \( n = 42 \)). The effects of engaging with a SDSS that provides real-time feedback, a monitoring SDSS and financial incentive, and a SDSS providing combined real-time feedback and a financial incentive for use were then examined (Study 6, \( n = 56 \)). Last, the potential for SDSSs to distract drivers was assessed by a study which measured performance on a Peripheral Detection Task (PDT) while driving with a SDSS providing real-time, visual feedback alerts (Study 7, \( n = 51 \)).

Findings: Overall, results indicated that young drivers rate SDSSs as acceptable for use, and that this acceptance is primarily influenced by perceptions of gains and social influence factors. In terms of efficacy, findings pointed to three conditions in particular under which
driving performance improved: 1) when the SDSS provided monitoring alone; 2) when monitoring was offered in conjunction with a financial incentive, or; 3) when monitoring was combined with real-time feedback and a financial incentive. During the final study, which addressed distraction however, slower reaction times and missed stimuli on a PDT emerged under SDSS real-time feedback conditions.

**Conclusions:** These findings suggest that SDSSs have potential value in mitigating young driver risk. However, any value offered by SDSSs in terms of reducing speeding and other forms of rule violations must be considered against the potential for systems that offer real-time feedback to lead to driver distraction.

**Implications:** The findings of these studies have implications for SDSS design and functionality, promotional campaigns, and future research needs, such as longitudinal distraction Field Operational Tests (FOTs).
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List of Abbreviations

AIC: Akaike Information Criterion
AMOS: Analysis of Moment Structures
ANCIS: Australian National Crash In-depth Study
ANOVA: Analysis of Variance
ASIRT: Association for Safe International Road Travel
BAC: Blood Alcohol Content
BCT: Behaviour Change Technique
BFNE: Brief Fear of Negative Evaluation
BI: Behavioural Intention
BMIS: Brief Mood Introspection Scale
CASP: Critical Appraisal Skills Programme
CDC: Centre for Disease Control
CFA: Confirmatory Factor Analysis
CFI: Comparative Fit Index
CI: Confidence Interval
C-TAM-TPB: Combined Technology Acceptance Model and Theory of Planned Behaviour
DALI: Driver Activity Load Index
DBQ: Driver Behaviour Questionnaire
DTMR: Department of Transport and Main Roads
EFA: Exploratory Factor Analysis
EPM: Electronic Performance Monitoring
FMRI: Functional Magnetic Resonance Imaging
FNE: Fear of Negative Evaluation
FOT: Field Operational Test
GDL: Graduated Driver Licensing
GDP: Gross Domestic Product
GPS: Global Positioning System
HCI: Human-Computer Interaction
HE: Human Error
HFE: Human Factors and Ergonomics
IDT: Innovation Diffusion Theory
IVDR: In-Vehicle Data Recorder
KMO: Kaiser-Mayer-Olkin
LED: Light-Emitting Diode
MCQ: Monetary Choice Questionnaire
MM: Motivational Model
MPCU: Model of PC Utilisation
MRT: Multiple Resource Theory
NHTSA: National Highway Traffic Safety Administration
NICE: National Institute for Health and Clinical Excellence
OC: Operant Conditioning
PABAK: Prevalence and Bias Adjusted Kappa
PAF: Principle Axis Factoring
PDA: Personal Digital Assistant
PDT: Peripheral Detection Task
PFC: Prefrontal Cortex
PRISMA: Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PTSD: Post-Traumatic Stress Disorder
QOL: Quality of Life
RCT: Randomised Control Trial
RMDLP: Relative Mean Difference Lateral Position
RMSEA: Root Mean Square Error of Approximation
ROI: Republic of Ireland
RSA: Road Safety Authority
RSME: Rating Scale of Mental Effort
RTC: Road Traffic Collision
SCT: Social Cognitive Theory
SDLP: Standard Deviation of Lateral Position
SR: Self-Regulation
SRE: Self-Regulatory Exertion
SRQ: Self-Regulation Questionnaire
SSRQ: Short Self-Regulation Questionnaire
SEM: Structural Equation Modeling
SDSS: Smartphone Driver Support System
SPSS: Statistical Package for the Social Sciences
TA: Technology Acceptance
TAL: Technology Adoption Lifecycle
TAM: Technology Acceptance Model
TDSS: Teen Driver Support System
TPB: Theory of Planned Behaviour
TRA: Theory of Reasoned Action
TRID: Transport Research International Documentation
UTAUT: Unified Theory of Acceptance and Use of Technology
WHO: World Health Organisation
Preface

Background

Approximately 1.24 million people are killed in Road Traffic Collisions (RTC) each year globally, with an additional 20-50 million people experiencing debilitating, often permanent, injuries due to such incidents (World Health Organisation, 'WHO', 2015). Young drivers under the age of 25 are consistently overrepresented in the road safety collision, casualty and fatality statistics. In the ROI for example, drivers aged 16-25 accounted for 25% of the total driver fatalities in 2014, a figure far higher than that for any other age group (e.g. drivers aged 36-45 accounted for 13% of total driver deaths; RSA, 2014). Such statistics mirror global trends (e.g. in the UK: Clarke, Ward, & Truman, 2005; Spain: Gras, Font-Mayolas, Planes, & Sullman, 2014; New Zealand: Gulliver & Simpson, 2007; the United States; McCartt & Teoh, 2015; Switzerland: Scagnolari, Walker, & Maggi, 2015; Israel: Toledo, Farah, Morik, & Lotan, 2014).

Research has indicated that the use of ‘black box’ in-vehicle data recorders (IVDRs) can significantly improve young driver behaviour and outcomes through providing real-time, and post-journey, safety feedback to drivers, and incentives for safe driving behaviours (e.g. Bolderdijk, Knockaert, Steg, & Verhoef, 2011; Carney, McGehee, Lee, Reyes, & Raby, 2010; McGehee, Raby, Carney, Lee, & Reyes, 2007; Musicant & Lampel, 2010). Most recently, an alternative form of IVDR monitoring has been developed, and is described in the current programme of research as a ‘Smartphone Driver Support System’ (SDSS). A SDSS is an innovative smartphone application (or ‘app’) designed to harness the advanced sensors of modern smartphones to similarly monitor and provide real-time and post-drive feedback support to young drivers (e.g. see Creaser, Hoglund, Manser, & Donath, 2009). Typically, such an app is downloaded for free, or at low cost, onto a personal smartphone which is then docked into position on a vehicle’s dashboard/windshield. The SDSS then provides visual (e.g. a flashing speed limit sign to indicate speeding) and/or audio (e.g. a beep to denote unsafe following distance) real-time feedback to young driver users. Journey records are also typically logged online to a personal account (e.g. a webpage or app profile), and post-journey feedback and recommendations on how to improve and promote safer driving can be provided. Increasingly, insurance companies are offering SDSSs to young driver consumers, with the promise of insurance discounts for safe driving records over time.

There is an almost complete absence of academic publications on SDSSs to confirm any proclaimed protective effects however. To date, two brief usability reports of a potential
smartphone support system have been produced (Creaser, Gorjestani, Manser, & Donath, 2011; Creaser et al., 2009) which suggest SDSSs may be received positively by young drivers, and may influence driving behaviour in a beneficial way. The aim of the current programme of research is thus to empirically evaluate the use of SDSSs in a young driver context in the Republic of Ireland (ROI). To do so, three key research themes, and focuses were identified: 1) the need to examine young driver acceptance of SDSS technology; 2) the need to assess the efficacy of SDSSs in mitigating young driver risk; and, 3) the need to address the issue of SDSS use and young driver distraction.

Of note, this programme of research adopts a primarily social psychological approach to understanding SDSS use, though the investigation into driver distraction was also broadly informed by theory and research from the Human Factors and Ergonomics (HFE) literature. That social psychology formed the dominant paradigm for the research, reflects a keen interest on the part of the researcher in the role of attitudes and beliefs, and internal psychological mechanisms, such as self-regulation, in shaping technology acceptance and efficacy, and her passion for evidence-based safety promotion in applied domains. It also reflects the core interests of the Risky and Extreme Behaviour research group at NUI Galway, and more broadly, an on-going collaboration between NUI Galway and the Road Safety Authority of Ireland to prevent loss of life on Irish roads.

**Thesis Overview**

This thesis presents a total of ten chapters, consisting of five distinct sections (A-E, see Figure 1 below). The first, Section A, presents an introduction to the current programme of research (Chapters 1 - 2). Section B then, presents the first series of empirical studies of the thesis, designed to assess young driver acceptance of SDSS technology (Chapters 3 - 4). Following this, Section C describes the next series of research studies, examining the efficacy of SDSSs in mitigating young driver risk-taking (Chapters 5 - 8). The fourth section (Section D) addresses the potential issue of young driver distraction when engaging with SDSSs, including an empirical study examining this (Chapter 9). Last, Section E (Chapter 10) features a succinct, final discussion of the overall programme of research.
Figure 1. Thesis structure, detailing the five sections (A-E) and chapter descriptions.
Overview Section A - Context
Chapter 1 introduces the road safety literature, with particular emphasis on exploring young driver risk, and the potential for emerging in-vehicle monitoring technologies to mitigate this. Chapter 2 then, details the rationale and key research questions that guided the research study designs, and thesis content and structure.

Overview Section B - Acceptance
In seeking to assess young driver acceptance of SDSSs, this section first features Chapter 3, which reports the findings of a systematic review (Study 1) assessing the factors influencing young driver acceptance and adoption of in-vehicle monitoring devices. Chapter 4 then, tests a novel structural model of young driver acceptance of SDSSs (Study 2), drawing from the findings of Study 1. A summary of the SDSS acceptance research and findings emerging from this section is then presented.

Overview Section C - Efficacy
Section C seeks to examine SDSS efficacy in a young driver use context. Chapter 5 describes a systematic review (Study 3) of the existing empirical studies examining the efficacy of in-vehicle monitors in mitigating young driver risk-taking. Chapter 6 then, introduces the concept of laboratory-based simulated driving, and details the findings of two empirical studies investigating the period of adaptation to (Study 4a), and validation of (Study 4b), the novel driving simulator obtained in order to safely examine SDSS efficacy. Following this, Chapter 7 describes the results of an assessment of the impact of SDSS monitoring on young driver behaviour in a simulated environment (Study 5). Chapter 8 then, outlines findings regarding the effects of engaging with real-time SDSS feedback and financial incentives in addition to SDSS monitoring while driving the simulator (Study 6). Last, a concise summary of the findings of the efficacy section is presented.

Overview Section D - Distraction
Chapter 9 introduces the issue of young driver SDSS distraction, and then reports on an empirical study (Study 7) conducted to begin to address this issue, by assessing performance on a Peripheral Detection Task (PDT) while drivers received real-time SDSS visual feedback. A final, brief summary section of the findings in relation to SDSS distraction is then outlined.

Overview Section E - Discussion
Chapter 10 provides an overview of each section of the current programme of research, briefly detailing each study, and discussing section-specific implications, and limitations, of
the study findings. Results are discussed in terms of application to SDSS design, future research needs, and their potential to inform policy and key stakeholders, such as insurance companies, road safety bodies and prospective young driver users.
Section A - Context: Why, and how, should young driver SDSS use be evaluated?

This section commences by providing a detailed background and context as to why young driver SDSS use currently needs to be evaluated (Section A1). It then describes the methodological approach and epistemology guiding the current programme of research, followed by a detailed outline of the proposed key research questions and studies, informed by the review of this literature (Section A2). Consideration is given to current RTC fatality and injury rates, and the overrepresentation of young drivers in these statistics. Explanations for their high RTC rates are provided, and discussed with regard to the limitations of current interventions designed to target and reduce these. The potential of SDSSs as a unique, novel means of decreasing young driver RTC incidence is then outlined, and discussed. Building from this body of literature, the key research questions and aims, and methodological approach, proposed to thoroughly evaluate young driver SDSS use, are then discussed and outlined.
Chapter 1 - Section A1: Young Driver Risk, Associated Factors and Mitigation Strategies.

A1.1 Introduction
This first chapter provides a context for the current programme of research by outlining the prevalence and costs of RTCs worldwide (Section A1.2). A key focus on young driver risk is then provided, and their overrepresentation throughout the global road traffic fatality and injury statistics is described (Section A1.3). The factors implicated in contributing to young drivers’ high levels of RTC vulnerability are presented (Section A1.4), and the high-risk driving behaviours engaged in by young people are discussed (Section A1.5). This is followed by a concise, critical overview of current intervention strategies implemented to target these behaviours, and factors to mitigate young driver risk (Section A1.6). Last, conclusions based on the material presented during this first chapter are provided (Section A1.7).

A1.2 Road traffic collisions
Road traffic collisions have been recognised as a significant national, and international, public health issue. The WHO estimate that 1.24 million people are killed ‘on the roads’ each year, with up to 50 million more experiencing debilitating mental and/or physical health problems as a result of the trauma associated with RTC involvement (Kenardy, Heron-Delaney, Warren, & Brown, 2015; WHO, 2013; 2015). While decreases in fatalities have been reported in a number of countries (including Ireland), in recent years, it has been predicted that RTCs will remain a primary cause of death globally and potentially result in up to 1.9 million deaths each year by 2020, unless additional road safety measures are adopted (European Commission, 2015, WHO, 2015).

The financial costs associated with RTCs are substantial. Estimates suggest that between 1-3% of a country’s Gross Domestic Product (GDP) is typically spent per annum in the aftermath of RTCs, at approximately $518 billion annually (WHO, 2004; 2009). In Ireland in 2013, for example, RTC-related costs amounted to an estimated minimum of €910 million (Rafferty, 2014). Figures from 2012 in the United Kingdom report costs of £15.1 billion (Lloyd, Wilson, Tuddenham, Goodman, & Bhagat, 2013). The annual RTC cost in the United States is at approximately $230.6 billion per annum, with recent 2010 figures recording $242 billion in RTC-related expenses (Association for Safe International Road Travel, ‘ASIRT’, 2016; Blincoe, Miller, Zaloshnja, & Lawrence, 2015).
Behind the financial implications, however, are the societal and personal costs accrued through RTC death and injury. Increased demand on hospital services, damage to national primary roads, productivity losses for employers, for example, can all amass in the aftermath of RTCs. On a more personal level, RTC injuries resulting in pain, or acquired disability, may also lower quality of life (QOL), as may the emotional consequences of RTC involvement. Post-traumatic stress disorder (PTSD) is often experienced following a RTC for example (Chossegros et al., 2011; Shaikh al arab et al., 2012), and anxiety disorders, depression and substance abuse are also common consequences of such trauma among survivors, and among relatives of victims (e.g. see Ehring, Ehlers, & Glucksman, 2006; WHO; 2004). Losses in personal capacity for earning, and education attainment can also occur. In addition, the process of seeking compensation in the wake of a RTC can be a uniquely stressful and lengthy process (e.g. undergoing multiple medical assessments), with observed negative physical and mental health outcomes (e.g. see Elbers et al., 2013).

A study by Hours et al. (2013), for example, found that of 886 individuals who had been injured in a RTC, at one year post-collision, 20% of the entire cohort still reported experiencing constant pain. In addition, more than half of those severely injured in a RTC reported negative impacts on the everyday lives of their family, and further impacts on leisure, projects and emotional life (e.g. this sub-group reported elevated incidence of PTSD), sexual difficulties and significantly higher rates of mean time off work in the past year (245 +/- 158 days, versus 75 +/- 104 days) than those with mild-to-moderate injuries, with 32% not having returned to work one year later.

**A1.3 Young drivers at increased risk**

Young drivers (i.e. those under the age of 25) have been identified as a particularly vulnerable driving group (Ouimet et al., 2015; Scagnolari et al., 2015; Scott-Parker & Proffitt, 2015). Close to half a million young people are killed in RTCs every year, and RTCs have been acknowledged as both the leading cause of death for all those aged between 15-29 years worldwide, and as a leading cause of acquired disability for young people (McDonald, Curry, Kandadai, Sommers, & Winston, 2014; WHO, 2004). In Ireland in 2014, for example, drivers between the ages of 16-25 accounted for 25% of the total number of driver fatalities that year, a greater proportion of fatalities than any other age group (e.g. drivers aged 36-45 accounted for 13% of total driver deaths; RSA, 2014). In addition, previous figures have indicated that this age group typically accounts for just 11% of the total Irish licensed driving
population (M. O’Connor, personal communication, 15th March, 2012). The over-representation of young drivers in RTC fatalities has been documented across the globe (in the UK: Clarke et al., 2005; Spain: Gras et al., 2014; New Zealand: Gulliver & Simpson, 2007; the United States: McCartt & Teoh, 2015; Switzerland: Scagnolari et al., 2015; Israel: Toledo et al., 2014).

In particular, the first 6-12 months of solo, licensed driving (i.e. driving unsupervised by a licensed other, as is typically a legal requirement prior to licensure) has been identified as the most dangerous period of time for a young driver (e.g. Curry, Pfeiffer, Durbin, & Elliott, 2015; McCartt, Teoh, Fields, Braitman, & Hellinga, 2010b; McDonald, Goodwin, Pradhan, Romoser, & Williams, 2015; McKnight & McKnight, 2003; Roman, Poulter, Barker, McKenna, & Rowe, 2015). Young males are more likely to be implicated in crashes, although young female driver risk is still high relative to other female and driving demographic groups (e.g. Monárrez-Espino, Hasselberg, & Laflamme, 2006; Prato, Toledo, Lotan, & Taubman - Ben-Ari, 2010). Interestingly, the pattern of decreasing crash risk during this initial 6-12 month period of licensed driving for young drivers has been reported to resemble the standard learning curve to describe increasing improvement of complex cognitive tasks over time (McDonald et al., 2015).

A1.4 Explanations for increased risk among young drivers

Explanations for the increased risk of RTCs among young drivers have typically focused on two key themes, which are addressed in the sub-sections that follow. First, young drivers have less driving experience than older drivers, and thus, less developed driving skills (e.g. speed selection and maintenance, hazard perception, collision avoidance etc.) which have been found to influence RTC likelihood (Curry et al., 2015; McDonald et al., 2015; Yamani, Samuel, Knodler, & Fisher, 2016). A second stream of research has focused on the increased propensity of young people to engage in various forms of risky behaviour (including risky driving, e.g. speeding) for a variety of reasons, such as to experience various positive emotions while driving, often referred to as ‘thrills’ (Gheorghiu, Delhomme, & Felonneau, 2015; Scott-Parker, Hyde, Watson, & King, 2013).

A1.4.1 Lack of driving experience. As stated, young drivers are typically less experienced drivers than other road users. Driving is a highly complex process, and the executive functioning skills required to successfully and safely manage diverse traffic situations can take years to develop (Deery, 1999; Pradhan et al., 2005; M. S. Young, Birrell,
Research focusing on the impact of experience (or lack thereof) on driving risk has focused on: 1) The relative underdevelopment of automaticity in the driving task amongst young and novice drivers; 2) The removal/lack of supervised driving during this time; and, 3) Optimistic biases that can arise in the absence of critical appraisal of performance.

First, young drivers can struggle (initially at least), to fully interpret the complex driving environment, identify potential road safety hazards and select suitable risk mitigation actions - cognitive processes that become increasingly automated and seamless with time and experience, but are not yet fully developed in novices (Holt & Rainey, 2002; Sagberg & Bjørnskau, 2006; Yeung & Wong, 2015). Ultimately this can lead to driver error, and heightened risk of RTC involvement. A study of police reports of over 2000 non-fatal RTCs involving 16-19 year old novice drivers (McKnight & McKnight, 2003), for example, indicated that the majority of RTCs examined were due to young driver’ failures to employ standard, safe operating practices, or to recognise and adequately respond to hazards (such as errors in visual search).

On a second level, novice and young drivers rely on accurate feedback to develop optimal, safe driving skills. Receiving information about the consequences of one’s actions is crucial for learning, and to foster the regulation of any incorrect and potentially unsafe driving behaviours, thus minimising the potential for RTC involvement (Dogan, Steg, Delhomme, & Rothengatter, 2012). However, in most jurisdictions, this feedback and support ends when young drivers transition from being accompanied while learning to drive, to being solo-drivers upon licensure, potentially before full mastery and automaticity of driving skills and manoeuvres has been achieved. In the ROI, for example, a young driver can drive unsupervised once they have passed their practical driving test, at which point they may have only been driving (while supervised) for six months in total. In the absence of protective, objective feedback, drivers can fail to appreciate unsafe driving, poor driving styles can become embedded and this can lead to increased collision risk (Dogan et al., 2012; Fuller, 1991; Kuiken & Twisk, 2001).

Third, and related to the previous point, young drivers are more likely than other demographic driving groups to possess optimistic biases regarding their driving skills, wherein they regularly overestimate their abilities to successfully navigate complex driving situations and/or manoeuvres, failing to appreciate the dangers hazards pose (De Craen, Twisk, Hagenzieker, Elffers, & Brookhuis, 2011; Molina, Sanmartín, & Keskinen, 2013; White, Cunningham, & Titchener, 2011). The driving environment can be a forgiving one, in
the sense that not every driver error results in a RTC, nor does every traffic rule violation result in a penalty (Dogan et al., 2012). However, that every error does not have immediate negative consequences should not mean they are ignored, or go unnoticed. Objective feedback is crucial in this scenario, to dispel such erroneous beliefs and foster awareness of realistic capabilities, discouraging young drivers from engaging in high-risk or demand behaviours with likely negative outcomes, such as speeding.

**A1.4.2 Propensity for risk-taking.** The research literature has also documented higher levels of intentional risk-taking (i.e. purposeful engagement in high-risk driving behaviours, such as driving while intoxicated or driving above the speed limit) amongst subgroups of drivers aged 18-24, which increases collision risk (e.g. Freydier, Berthelon, Bastien-Toniazzo, & Gineyt, 2014). Risk-taking amongst this young driver demographic has been attributed to complex interactions between cognitive, developmental/social factors and personality traits, and how these factors lead to excitement and sensation seeking behaviours (i.e. risk-taking). Although a comprehensive review of all of these factors (and potential interactions) is outside the scope of the current programme of research, the following themes have dominated the research literature to date: 1) The influence of neurodevelopmental processes during this time period; and, 2) The relationship between certain personality traits and risky driving propensity.

First, studies from the field of cognitive neuroscience suggest that young people under the age of 25 are neurologically predisposed to engage in risk-taking behaviours. The dual-process model (Steinberg, 2008), a prominent theory of the phenomenon of adolescent risk-taking, purports that at this stage in life, structural and functional brain development is still on-going, while the motivational system (responsible for sensitivity to rewards) becomes increasingly active. In particular, brain areas such as the prefrontal cortex (PFC) are not fully developed when under the age of 25, an area which is known to govern cognitive control, including rational decision-making, response inhibition and action planning (Fryt & Czernecka, 2015; McCormick, Qu, & Telzer, 2016). Likewise, changes and increased activation in motivation-related areas such as the accumbens or the dopaminergic system during this time period have been consistently linked to greater reward-seeking behaviours (e.g. see Fryt & Czernecka, 2015; Galvan, Hare, Voss, Glover, & Casey, 2007). As such, risk-taking can be understood to manifest at this time due to an imbalance between a hyperactive motivational system, and underdeveloped cognitive control neural systems, responsible for inhibition of risky responses when seeking to attain desirable rewards.
This has been observed with regards to young driver risk-taking and behaviours across a number of empirical research studies. It has been suggested that findings in relation to the negative influence of peer passengers on young driver risk-taking for example, can be understood when considering that adolescence and young adulthood mark a period of development when an individual is most attuned to opportunities to gain social rewards in the form of approval for desired behaviours (D. Albert, Chein, & Steinberg, 2013; Chein, Albert, O’Brien, Uckert, & Steinberg, 2011; Galvan et al., 2007). Given that driving norms among teen/young adult peers typically favour risk-taking rather than safe driving (e.g. Shope & Bingham, 2008), if young drivers are aware of and desire social reinforcement in the driving context while lacking the developed neurological capacity to control these urges, then the presence of passengers may likely increase risky driving behaviour. A study by M. Gardner and Steinberg (2005) for example, found that for teens and young adults (18-22 years old), driver risk-taking in a simulator increased by 50% in the presence of peers, however, this was not observed in adult drivers. Typically, young drivers have been found to drive faster, and with reduced headway, when peer passengers are accompanying them, and are more likely to drink and drive (C. Lee & Abdel-Aty, 2008; Simons-Morton, Lerner, & Singer, 2005). In addition, Functional magnetic resonance imaging (fMRI) studies have also documented increased activity in reward-related, adolescent brain regions such as the ventral striatum and orbitofrontal cortex when completing a driving-related task in the presence of peers, and less activity within cognitive control areas as compared to older adults (Chein et al., 2011).

Second, research has focused on personality traits, and their relationship with risky young driver behaviour(s). Younger people (and young drivers) have been found to report higher levels of risk-related personality traits including extraversion, impulsiveness, and sensation-seeking, and lower levels of prosocial behaviour-related traits, such as agreeableness or conscientiousness, than older adults, all of which have been found to render in-vehicle risk-taking (and risk-taking in general) more likely (e.g. Constantinou, Panayiotou, Konstantinou, Loutsiou-Ladd, & Kapardis, 2011; Ehsani et al., 2015; Luengo Kanacri et al., 2014; Roberts, Walton, & Viechtbauer, 2006; Taubman-Ben-Ari, Kaplan, Lotan, & Prato, 2016). Young male drivers in particular have reported higher levels of a number of these risky traits than young female drivers (e.g. Arnett, 1994), and greater enjoyment of driving and engaging in risky driving manoeuvres (Blows, Ameratunga, Ivers, Lo, & Norton, 2005; Rhodes & Pivik, 2011b). Young males also tend to report more frequent and intense experiences of driver anger (in circumstances of congestion, or experiencing poor road conditions for example) than other driving groups, which has been found to relate to greater
risk-taking and poorer driving outcomes, in line with statistics documenting their heightened RTC risk (Delhomme, Chaurand, & Paran, 2012; Greaves & Ellison, 2011; Taubman-Ben-Ari et al., 2016).

**A1.5 Young drivers and specific forms of risky driving**

It must be noted that there are a number of different forms of young driver risk-taking and reckless driving behaviours that may lead to the inflated crash risk in this group. Distinguishing between these is crucial in order to design targeted, effective interventions, as increasingly, research is suggesting that each of these behaviours are each motivated by different factors (Fernandes, Hatfield, & Soames Job, 2010; Fernandes, Job, & Hatfield, 2007; Taubman-Ben-Ari, Mikulincer, & Iram, 2004). A young driver’s reasons for engaging in speeding, for example, may not also result in the occurrence of drink driving, or their decision to tailgate another driver. In all, driving while fatigued, distracted, intoxicated (i.e. with a Blood Alcohol Content [BAC] above the legal limit, or under the influence of narcotics) or while speeding, have been identified as four of the most distinct, risky, driving-related behaviours in terms of their contributions to RTC likelihood, and negative, health-related outcomes (e.g. Fernandes et al., 2010). In the context of young driver risk, driver speeding has been identified as the most dangerous and high-risk behaviour that can be engaged in.

**A1.5.1 Young driver speeding.** As stated, driver speeding has emerged as a core, contributing factor to young driver RTC likelihood. As referred to here, this constitutes driving faster than the legal speed limit. This differs from ‘fast driving’, which refers to driving too fast to cope with road and weather conditions, while not necessarily breaking speed limits (Gheorghiu et al., 2015). Overall, speeding has been recognised as the most frequent, and dangerous traffic violation committed by drivers (Gheorghiu et al., 2015; Hassan & Abdel-Aty, 2013), including young drivers; a trend observed worldwide (Delhomme, Cristea, & Paran, 2014; Delhomme, Verliiac, & Martha, 2009; Scott-Parker et al., 2013). Speeding substantially increases the likelihood of a RTC occurring, and the severity of injury sustained if a crash does take place (i.e. whether a RTC results in fatalities or injuries, e.g. Hatfield, Fernandes, Faunce, & Job, 2008; Viallon & Laumon, 2013).

Kloeden, McLean, Moore & Ponte, (1997) found that RTC risk doubles with each 5km/h increase in speed above a 60km/h speed limit, for example. Similarly, it has been proposed that an average reduction of 2-5km/h could reduce between 10-30% of RTC-related injuries
if a collision occurs (Molin & Brookhuis, 2007). Ultimately, the higher the speed at which a person is driving, the shorter the time window they have to react to any environmental changes, the longer the vehicle’s stopping distance, and the greater the reduction in manoeuvrability to avoid hazards (Aarts & van Schagen, 2006; Garvill, Marell, & Westin, 2003; Hatfield et al., 2008). All of these contribute to heightened risk of a fatal RTC.

Regarding young drivers, engaging in speeding is particularly dangerous as their reaction times, hazard perception skills and extent of operational control over the vehicle are typically relatively underdeveloped (e.g. McDonald et al., 2015). Statistics from fatal young driver crashes in the United States across 2007-2009, for example, indicate that 37% of young male drivers, and 25% of young female drivers were driving too fast (i.e. either speeding or driving too fast for conditions) prior to collision (Swedler, Bowman, & Baker, 2012). In Australia, a study published in 2011 (accounting for the years 2005-2010), found that speeding contributed to 30.2% of young driver or rider RTC fatalities in Queensland (Department of Transport and Main Roads, 'DTMR', 2011). Despite this, young drivers have been documented as regarding speeding as one of the least serious or dangerous traffic offences (e.g. Parker, Stradling, & Manstead, 1996; Rothengatter, 1991), and one that they report frequently committing (Mullen, Maxwell, & Bédard, 2015). An Australian study, for example, reported that young males reported driving at a speed 10km/h above the limit on half of their recent journeys (Vassallo et al., 2007). Laboratory based simulator studies have also reported numerous instances of young driver speeding (e.g. de Winter, 2013; Prabhakaran & Molesworth, 2011; K. L. Young, Regan, Triggs, Jontof-Hutter & Newstead, 2010).

Although the motivations behind young driver speeding are complex, they are understood to arise primarily due to optimism biases regarding their capability to manage driving at high speeds (Gosselin, Gagnon, Stinchcombe, & Joanisse, 2010; White et al., 2011), and their (previously described) propensity towards sensation and reward-seeking (e.g. Fryt & Czernecka, 2015; Jongen, Brijs, Komlos, Brijs, & Wets, 2011). Research indicates that young drivers who speed typically consider themselves as capable of driving at high speeds, and that this act is a demonstration of their driving skills when in the presence of others, which can improve their social status (Horvath, Lewis, & Watson, 2012; Knight, Iverson, & Harris, 2013). They may also derive emotional (e.g. pleasure and ‘thrills’ in driving fast) and practical/instrumental (e.g. saving time in travelling to a destination) benefits and rewards in speeding (Cestac, Paran, & Delhomme, 2011). Last, evidence suggests that speeding becomes a habitual behaviour, with past speeding tendencies...
predicting subsequent speeding (De Pelsmacker & Janssens, 2007). Clearly, driver speed must be a focal point for young driver risk mitigation strategies if they are to tackle the issue of young driver RTC involvement.

A1.6 Addressing young driver risk

Current popular strategies to reduce young driver road deaths include education campaigns, mass media communication (particularly the use of threat appeals), the implementation of GDL, IVDRs, and, most recently, SDSSs. These typically aim to target single, or multiple, factors contributing to young driver RTC risk. Education campaigns, for example, typically strive to generate awareness of the outcomes of risky behaviour (with the aim of changing attitudes and motivation towards unsafe practices), present alternatives to dangerous driving, and teach driving skills (e.g. Begg & Brookland, 2015; Brijs, Cuenen, Brijs, Ruiter, & Wets, 2014). Threat appeals then, aim to arouse fear such that a driver is more amenable to persuasive messages recommending actions to avoid the dangerous behaviour, and thus reduce fear (Taubman-Ben-Ari, Florian, & Mikulincer, 2000). A critical overview of these approaches is now presented.

A1.6.1 Education campaigns. The efficacy of young driver education campaigns/courses has been the subject of much debate within the driving research literature (e.g. af Wåhlberg, 2010; Brijs et al., 2014; Zakrajsek et al., 2013). Such programmes are typically provided in a school or classroom environment to pre-licensed drivers. The majority often combine the provision of information on topics such as driving rules and regulations, vehicle operation and safety, and known risk factors to affect driving (such as intoxication behind the wheel, distraction, speeding etc.) in conjunction with simulated training, or brief on-road practice with a qualified instructor (Shell, Newman, Córdova-Cazar, & Heese, 2015; D. Thomas, Bloomberg, & Fisher, 2012). In the ROI, driver education primarily includes school-based activities (i.e. no on-road training) wherein materials are provided by the RSA to teachers. The ‘Streetwise’ programme for example, is a 12-week course targeted at 12-15 year olds that covers topics such as speeding, hazard perception and driving fatigue. Similarly, ‘Your road to safety’ consists of a 45 hour (or 20 hour fast track) programme designed for 16-18 year olds to provide enhanced information on Streetwise topics, including novel information in relation to road safety enforcement, drug driving, and licensing and insurance issues.
Unfortunately, empirical evaluations of education effectiveness in mitigating driver risk-taking (in terms of fewer crashes and traffic violations) have tended to be unsystematic, and limited in both quality and quantity (e.g. see Beanland, Goode, Salmon, & Lenné, 2013b; Lonero & Mayhew, 2010 for review). Overall however, amongst the number of systematic and literature reviews published on the topic, ‘reviewers of the evaluation literature have typically concluded that beginner driver education has yet to demonstrate clear success in improving safety of new drivers’ (Lonero & Mayhew, 2010, p. 38), with many studies reporting no clear protective effects, or even increased crash rates (Peck, 2011). Ultimately, driver education programmes are often not designed in line with behaviour (or attitude) change theories, and while instruction can be helpful in developing cognitive and psychomotor skills, better knowledge and skills do not automatically result in fewer RTCs (Peck, 2011; A. F. Williams, Preusser, & Ledingham, 2009). Even better trained, skilled drivers must want to drive safely if they are to avoid RTCs. Young driver motivation and willingness to take risks for potential reward is of key importance, and must be acknowledged and targeted.

A1.6.2 Persuasive communications - Threat appeals. Road safety advertising campaigns targeted at young drivers (and particularly young males) frequently employ communications designed to change behaviour and attitudes through the use of threatening material (i.e. ‘threat appeals’, Shehryar & Hunt, 2005; Taubman-Ben-Ari, Florian, & Mikulincer, 2000). Within a road safety context, threat appeals typically attempt to discourage young drivers from engaging in risky behaviour by presenting graphic representations of the negative consequences that can occur as a result of this (typically serious or fatal injuries due to involvement in a RTC). These will also generally recommend a behaviour to reduce the likelihood of this occurring, such as advising young drivers to slow down and/or drive within the speed limit on the roads (e.g. see Guttman, 2015). Young drivers’ responses to these appeals depend on their appraisals of the threat’s severity and how vulnerable they perceive themselves to be to it, their appraisal of the prospective effectiveness of the suggested safety method to avert the threat (i.e. response efficacy), and their perceived capacity to employ this (i.e. self-efficacy, Brijs et al., 2014; Guttman, 2015; Lewis, Watson, & White, 2010).

As with educational campaigns however, empirical evaluation of threat appeals has been problematic (Hastings, Stead, & Webb, 2004). Overall, although recent research has highlighted certain conditions in which threat appeals can be effective (even amongst risky young male drivers), the greater driving research literature has reported inconsistent findings
with regards to threat appeal efficacy in a driving context (e.g. R. N. Carey & Sarma, 2011; Lewis et al., 2010; Taubman-Ben-Ari & Findler, 2003; Taubman-Ben-Ari et al., 1999), in addition to ethical concerns regarding their use (Guttman, 2015; Hastings et al., 2004). Threat appeals may, in very specific circumstances, reduce engagement in the targeted risky young driver behaviour. However, they still fail to address young, inexperienced drivers’ poor hazard perception, for example, and need for protective feedback to learn from errors, and in some cases, may even serve to increase young driver risk-taking due to defensive responses to the threatening material presented (e.g. R. N. Carey & Sarma, 2011).

**A1.6.3 Graduated Driver Licensing.** Due, at least in part, to the relatively disappointing results from early studies assessing the efficacy of driver education campaigns, and limited successes of persuasive communication in mitigating young driver risk, road safety and governmental bodies first began to turn towards Graduated Driver Licensing (GDL) practices in the 1960s in Australia, which soon spread to New Zealand, the US and greater Europe (Begg & Stephenson, 2003; Faulks & Irwin, 2009; Senserrick & Whelan, 2003). Varying forms of GDL are now in place across the world (Masten, Foss, & Marshall, 2013; Toledo et al., 2014). In essence, GDL is a risk management system that aims to ‘phase in’ novice, inexperienced drivers to eventual full driving privileges by controlling and delaying their exposure to progressively more complex driving situations (A. F. Williams, McCartt, & Sims, 2016). Although legislation for GDL differs from country to country, or even state to state (Fell, Todd, & Voas, 2011; A. F. Williams, Tefft, & Grabowski, 2012), the basic structure involves the implementation of a minimum learner period for a fixed period of months (e.g. six months in the ROI), which allows for accumulated practice driving under supervision of a licensed other. This is then followed by an intermediate licensing phase with restrictions on unsupervised, or potentially high-risk driving (e.g. restrictions on peer passengers, or late night driving) prior to full licensure. In doing so, beginners can be better protected while they are learning, in addition to protecting other road users. They can hone their skills and receive feedback on their driving, while avoiding more complex driving situations (e.g. driving in the dark at night, or with peers), and allowing their cognitive control abilities to develop, all of which should reduce RTC risk.

A large body of research, including comprehensive reviews, has established that GDL is effective in reducing young driver crash rates, with some studies reporting RTC reductions of up to 40% since implementation (L. H. Chen, Baker, & Li, 2006; Dee, Grabowski, & Morrisey, 2005; McCartt et al., 2010b; Shope, 2007; A. F. Williams & Shults, 2010). However, there are two difficulties with this body of literature. First, it is not clear if findings
are sustained after the GDL process, with concerns being voiced within the research literature that GDL may not actually improve driver behaviour, but rather delay exposure to high-risk traffic environments and RTC opportunity (McCartt, 2001; Preusser & Tison, 2007). It may be that young drivers gladly complete the different stages associated with GDL, for example, observing required restrictions and practicing safe driving during this, however they may do so primarily to acquire their licence, and as such, may not be motivated to drive safely once licensed. Research conducted by Masten and Foss (2010) would suggest that this is not the case. Using survival analysis, they established that 16 year olds licensed under the North Carolina GDL programme had lower first-crash risk than those licensed under the previous licensing system during the first five years post licensure (i.e. driving as an unsupervised driver). These reductions did not hold for those who received their licence at age 17 however, and more studies are required to ascertain if this finding replicates across jurisdictions and populations.

This points to the second difficulty with this research, regarding external validity of GDL findings. The majority of these studies have been conducted in the US, where teenagers begin the GDL process aged as young as 15 in some states, and for whom GDL is only an option to those aged 18 years and under (e.g. see S. P. Baker, Chen, & Li, 2007), and not the full, high-risk young driver demographic. This is relevant as empirical findings suggest that GDL may be less effective amongst older drivers (Ferguson, Teoh, & McCartt, 2007; A. F. Williams, Ferguson, & Wells, 2005). Ultimately, although positive GDL effects have been recorded within specific states or regions, amongst certain age groups, the general trend and overrepresentation of young drivers (aged 18-24) in the global RTC fatality and injury statistics has persisted for decades now, despite GDL implementation (Scott-Parker, King, & Watson, 2015). Novel solutions are clearly needed.

A1.6.4 In-Vehicle Data Recorders. In recent years, IVDRs, such as ‘DriveCam’, ‘Greenroad’, or ‘DriveDiagnostics’ devices (e.g. see Lotan & Toledo, 2007; McGehee et al., 2007; Prato et al., 2010) have emerged as a potential technological solution to address both young drivers’ need for feedback, and rewards to motivate safer driving behaviour. These are ‘black box’ monitoring devices physically installed in a young driver’s vehicle, to activate automatically upon ignition (K. L. Young, Regan, Mitsopoulos, & Haworth, 2003b). As such, IVDRs act to detect and record vehicular behaviour data (such as speed or braking manoeuvres etc.) and contextual environmental information (such as location) in transit, employing algorithms to match any unsafe driving patterns with pre-programmed driver support functions when detected (Guttman & Lotan, 2011). Supportive responses can range
from real-time, light-emitting diode (LED) feedback (e.g. from a green light to a flashing red to denote a speeding violation; Farmer, Kirley & McCartt, 2010; Simons-Morton et al., 2013), to audiovisual alerts (e.g. an onscreen flashing speed limit sign, and/or series of beeps that continue until speed is reduced; Creaser et al., 2009; Farmer et al., 2010), to physically limiting speed (i.e. restricting the maximum speed that a young driver can reach to ensure no dangerous violations can occur; K. L. Young et al., 2010). Detailed post-journey feedback on performance and any risky manoeuvres for past trips is also typically provided to the driver (or their parent), often featuring means of tracking performance improvements over time, and facilitating average comparisons with peers or other similarly aged drivers also driving with a device. In addition, insurance companies are now frequently providing IVDRs to young driver customers with the promise of discounted, cheaper insurance on receipt of safe driving records provided by the device, and for initially opting to drive with an IVDR installed (Bolderdijk et al., 2011). That is, IVDR use and safe driving are being incentivised to young drivers through this process, as a means of obtaining valued rewards (K. L. Young et al., 2003b).

As such, IVDRs provide protective, objective feedback, recommendations on how to build safe driving habits, and offer rewards to motivate safe, young driver behaviour. These are a relatively new technology however, and accordingly, a limited body of research is available to attest to their effectiveness in mitigating young driver risk-taking. Of the few published studies available, a number of these have reported decreases in young driver extreme driving manoeuvres (e.g. harsh acceleration or braking, curve navigation etc., Carney et al., 2010; McGehee et al., 2007; Musicant & Lampel, 2010) and reductions in speed when engaging with an IVDR and ‘Pay-As-You-Drive’ insurance (e.g. Bolderdijk et al., 2011). Despite such promising findings however, and the theoretical potential of IVDRs to tackle young driver risk-taking, reports have emerged that young drivers are often unwilling to adopt and use these devices. Concerns about purchase and subscription costs (if not provided by an insurer, these can cost several hundred euro), the need for specialist maintenance if any problems arise, the bulkiness of certain systems, and a dislike of devices that can unexpectedly intervene and limit speed are amongst the reasons being voiced by young drivers against IVDR adoption and use (e.g. Lerner et al., 2010; McCartt, Farmer, & Jenness, 2010a; K. L. Young et al., 2003b). Evidence of device tampering and destruction has also been recorded within the research literature, as has difficulty even recruiting participants to drive with the devices for research studies (Lahrmann et al., 2012; McCartt et al., 2010a; K. L. Young et al., 2010). Despite their potential, IVDRs will not reduce driver risk-taking if
young drivers are not willing to drive with them. A novel alternative to IVDR monitoring, the use of SDSSs, may prove a suitable solution for young driver use.

A1.6.5 Smartphone Driver Support Systems. Smartphone technology has evolved rapidly since its introduction to the telephones market in the 1990s, such that devices now possess a variety of high performance sensors including accelerometers, high resolution cameras and Global Positioning System (GPS) chipsets as standard (Pitt, Parent, Junglas, Chan, & Spyropoulou, 2011). A SDSS is a smartphone application or ‘app’ that harnesses these properties to enable a smartphone to function as an in-vehicle monitoring device, monitoring driver behaviour and providing both real-time, in-vehicle feedback, and post-journey, web or app profile-based summary reports (e.g. see Creaser et al., 2011; Creaser et al., 2009). A number of these have recently been made available for teen and adult driver download and use. Examples include the iOnRoad app (iOnRoad, 2016) which utilises a smartphone’s inbuilt sensors and GPS when mounted on a vehicle’s dashboard to give real-time, audio and visual warnings targeting speeding, forward collision, headway monitoring and lane departure. It provides online driver logs and minimises driver distraction by reading aloud texts and diverting calls while in transit. The iGuardian Teen, a young driver specific SDSS (iGuardianTeen, 2012) performs identical functions to the above, while also sending real-time parental alerts via text or email of dangerous manoeuvres detected while driving. Irish insurance companies have also recently released SDSSs, including Axa who have released their DriveSave app targeted at young driver consumers (Axa, 2016). DriveSave monitors driving, provides post-journey feedback and the potential to earn up to 30% off a premium upon receipt of safe driving records over one year for 17-24 year old customers.

These applications are typically inexpensive (e.g. the pro version of the iOnRoad app is currently available for €1.11) or free if provided by an insurer, as compared to high cost IVDRs, and can be downloaded with ease onto a personal phone similar to any other application. The smartphone is then docked onto a vehicle’s dashboard or windshield wherein it can provide visual (e.g. a flashing speed limit sign if speeding) and/or audio (e.g. a beep to denote unsafe following distance) feedback to young driver users. Journey records are also typically logged online to a personal, password-protected webpage or app profile, which features personalised recommendations on how to reduce unsafe behaviours. As the smartphone is not physically hardwired to the vehicle, it cannot directly impact on vehicle performance as an IVDR can (e.g. to limit the maximum speed of the vehicle), and it can be activated or deactivated at the will of the user.
In all, SDSSs represent an accessible, cost-effective and potentially more acceptable young driver alternative to IVDR usage, while still targeting key young driver risk factors. This is of great relevance as the young driver monitoring literature attests to the reality that young drivers often have an aversion to IVDRs (McCartt et al., 2010a; K. L. Young et al., 2010). Given that SDSSs operate in conceptually similar ways, and can be anticipated to change behaviour through identical mechanisms (i.e. providing feedback and external regulation of behaviour) as IVDRs, they can be regarded as holding promise in evoking positive young driver behaviour change.

As stated, SDSSs differ from IVDRs in certain ways however. Feedback alerts can be disabled more easily via a smartphone, for example, and an app that limits phone communication capability while driving may not be desirable to all young drivers. Concerns regarding the potential for young driver distraction when engaging with mobile phones while driving also abound, given the body of literature that has attested to the dangers of such interactions (Creaser et al., 2011; Creaser et al., 2009; J. D. Lee, 2007). Overall, despite their current availability for download and use from app stores, and national and international promotion via advertising, to date, no objective scientific research has been published to confirm any protective or beneficial effects of young driver SDSS use, or identify means to maximise this if proven safe. Given their potential to reduce young driver risk-taking by providing objective feedback on errors, while incentivising safe driving with insurance discounts, evaluative SDSS research is clearly warranted at this stage.

A1.7 Conclusions
Road traffic collisions are a critical national and international health concern, and fatality rates stand to deteriorate further in the next four years if additional actions are not taken (European Commission, 2015; WHO, 2015). Young drivers are a particularly vulnerable driving group who have been disproportionately represented throughout the global RTC fatality and injury statistics for decades (Scott-Parker et al., 2015). Overall, this is due to complex interactions between numerous risk factors, but the loss of protective feedback provided by supervising parents and/or driving instructors prior to licensure, and a lack of sufficient motivation or perceived reward in driving safely versus taking risks, have been identified as key factors impacting upon their high RTC involvement rates (e.g. Dogan et al., 2012). Many previous research and intervention approaches to reducing young driver RTCs, such as the use of educational campaigns, or IVDRs have not fully addressed these factors, or
have done so in a way that is not acceptable to this target young driver demographic.

The use of SDSSs represents a novel potential solution to this public health issue. They are an accessible, cost-effective technology that actively addresses young driver feedback and incentivisation needs by providing real-time and post-journey evaluations of performance, and are typically offered in conjunction with the potential to earn valuable insurance discounts. To date, there is an absence of any published, objective, scientific literature to affirm any such protective effects. Despite SDSSs being available for purchase, and promoted by insurance companies, it is not clear how acceptable for use young drivers deem them, for example, how effective they are in improving young driver behaviour, or whether they pose a risk of distraction to this vulnerable driving population. As such, SDSS-specific research is necessary at this stage in order to determine their value in mitigating young driver risk.
Chapter 2 - Section A2: Rationale, Aims and Research Questions

A2.1 Summary of literature

A number of key points emerged from the literature reviewed in Chapter 1. First, both national and international statistics, and extensive research indicate that young drivers (those aged 18-24 years) represent a high-risk driving group (Scott-Parker & Proffitt, 2015; Toledo et al., 2014). The factors influencing their overrepresentation throughout the road traffic fatality and injury statistics are both numerous and complex, relating broadly to cognitive, developmental, state and trait variables (Dahl, 2008; Pradhan et al., 2014). In particular, research would suggest that the loss of protective feedback provided by a supervising driver upon licensure can be detrimental to young driver outcomes (Dogan et al., 2012; White et al., 2011). Likewise, safe driving behaviour may need to be incentivised further in order to compete with the perceived rewards of engaging in risk-taking (such as peer approval, e.g. D. Albert et al., 2013) for young people.

Second, the implementation of SDSSs represents a promising young driver intervention that could address these issues. Existing research on conceptually similar IVDRs would suggest that this novel SDSS technology may have a positive impact on young driver behaviour (e.g. Carney et al., 2010; McGehee et al., 2007; Musicant & Lampel, 2010). Of note, SDSSs do differ from IVDRs in several ways however (e.g. they typically do not involve parents in the monitoring process, whereas IVDR interventions do; Axa, 2016). As such, in the absence of SDSS-specific research to attest to their protective effects, the fact that they are being advertised for use by insurance companies to this vulnerable young driver demographic is concerning. Little is known regarding how acceptable for use young drivers deem SDSSs, or how effective they are in mitigating risk-taking. Furthermore, across the driver monitoring literature in general, the potential theoretical mechanisms through which monitoring devices may have their effects (which could be harnessed to maximise any benefits) are also largely unknown.

Last, the potential for driver distraction when engaging with in-vehicle monitoring feedback has yet to be addressed empirically. This has been acknowledged as a substantial concern in relation to young, at-risk drivers who are particularly susceptible to in-vehicle distraction, as evidenced through the considerable body of literature attesting to the negative influences of young driver mobile phone use (Haque & Washington, 2015; J. D. Lee, 2007). At this stage, the need for an extensive, systematic evaluation of young driver SDSSs use is evident.
A2.2 Methodological considerations and rationale

Before presenting an overview of the current programme of research (Section A2.3, below), this section presents a rationale for the epistemological position and methodological approach that underpins this thesis. Succinctly put, the thesis makes the assumption that there is merit in approaching an evaluation of SDSSs through: 1) a predominantly social psychological lens, and; b) the experimental paradigm. The section considers both assumptions in the context of the research questions posed, but also explores alternative and complementary approaches that could have been pursued. First, the research questions are presented to set the context for the discussion that follows. Second, an overview of the epistemology underpinning social psychology in general, and experimental social psychology in particular, is presented. Last, alternative approaches that could have been adopted to explore and evaluate SDSSs are considered. Overall, this section confirms that the epistemology and methods selected for the current programme of research have good ‘fit’ with the research questions, while acknowledging the potential to probe related research questions through alternative, multidisciplinary approaches in future research.

A2.2.1 Research questions. Table 1, below, sets out the overarching research questions that guided the programme of research for this thesis. More detailed research questions, on a study-by-study basis, are then presented in Section A2.3.

Table 1

<table>
<thead>
<tr>
<th>Thesis Section</th>
<th>Research Question</th>
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<tr>
<td>Section B - Acceptance</td>
<td>• What factors, and broader model, predict young driver acceptance and adoption of a SDSS?</td>
</tr>
</tbody>
</table>
| Section C - Efficacy | • Does SDSS use reduce young driver risk-taking?  
• What are the underlying mechanisms influencing any observed behavioural changes when engaging with a SDSS?  
• Is the impact of SDSS use moderated by any individual variables? |
| Section D - Distraction | • Does real-time feedback cause young driver distraction? |
In examining these research questions, a fundamental consideration that arises for the researcher is: What type of epistemological stance and methodological paradigm is best suited to address these? The research questions presented indicate that specific hypotheses have been identified through reviewing the broader driving literature, and that the methodological solution should focus on prediction and testing causation, rather than exploration of phenomenology. This reflects the large volume of research on both IVDRs and other relevant technologies that provide sufficient theoretical and empirical material to presently develop specific research questions and hypotheses in this area (e.g. Guttman & Gesser-Edelsburg, 2011; Lerner et al. 2010; McCartt et al. 2010). A more exploratory approach, focused on the ‘lived experiences’ of SDSS users for instance, could offer valuable information, but not yield answers to these key research questions.

In summary, then, the research questions point towards quantitative methodological solutions for hypothesis testing. The next section considers the epistemology of Social Psychology and traditional social psychological scientific methods, and how this school of research provides good ‘fit’ with the research questions.

**A2.2.2 Epistemology of social psychology.** The current programme of research draws from the epistemology and ontology of Experimental Social Psychology. Experimental social psychology is founded on the assumption that it is possible to obtain accurate knowledge about human experience and behaviour in social settings (Chapman, 2007; Freyd, 1983; Sarin, 1986). It also assumes that it is possible to identify and study processes and phenomena that are universal, and viewed as operating at a psychological level - that is, at the level of an individual who may be influenced by the social context, but ultimately operates as a self-contained entity (Doise & Valentim, 2015; Figgou & Pavlopoulos, 2015; Murnighan & Wang, 2016). The core goal of experimental social psychology is to understand the relationships between the varying elements of the social world, and explain how they work.

To achieve this goal, experimental social psychologists seek to discover knowledge about social events, processes and phenomena using the scientific method, and the systematic collection and analysis of that which can be directly observed. Experimental social psychology is based on an ontology in which the social world is separate from, and external to, human action, and consists of discrete, observable events and phenomena that are lawfully related. Its epistemology then, is that true, objective knowledge can be gained about the universal laws of human behaviour and experience using the hypothetico-deductive method to provide nomothetic cause-and-effect explanations, wherein theory is used to generate an experimental hypothesis, that can then be tested by falsification, using a specified set of
variables selected for study, and excluding extraneous influences (Murnighan & Wang, 2016).

**A2.2.3 Methods in experimental social psychology.** Within social psychological research, broadly speaking, there are three main ways in which measurable data can be collected to test hypotheses, and answer research questions. First, self-report measures are commonly used to study attitudes, beliefs and social cognitions (e.g. Kervick, Hogan, O’Hora, & Sarma, 2015; Sarma, Carey, Kervick, & Bimpeh, 2013). These may be in the form of answers to a scale, questionnaire, or response to an interview question, and can be open or close-ended (e.g. using a Likert scale with responses ranging from ‘strongly agree’ to ‘strongly disagree’, such as in the Driver Behaviour Questionnaire, ‘DBQ’, Iversen, 2004). In experimental research, any open-ended responses or interview questions would be analysed using a pre-existing, validated coding scheme, allowing for quantitative analyses in relation to the hypothesis being tested (for wider discussion on such methods in social psychology see Berkowitz, 1977; Figgou & Pavlopoulos, 2015; Goldstein, 1980; Judd, 2001; Jussim, Crawford, Anglin, Stevens, & Duarte, 2016).

Second, observational measures refer to those taken from direct observation of a subject’s behaviour, relevant to the research question. These could include, for example, recording the duration of eye gaze in seconds as a measure of intimacy in a relationship, or the speed a young driver selects when driving with a peer to determine their level of influence (e.g. Kleinke, 1986). Last, given that issues with social desirability surround the use of self-reports (e.g. in the context of road safety research, see Wåhlberg, Dorn, & Kline, 2010), a range of implicit measures have been developed from which an individual’s thinking (including their unconscious thoughts) can be inferred indirectly. Experimental studies have examined implicit attitudes towards speeding for example (Hatfield et al., 2008), or crash-risk optimism (Harré & Sibley, 2007).

In terms of experimental settings for these kinds of studies, such research is typically conducted in laboratories or ‘in the field’ (so-called ‘field experiments’, e.g. naturalistic IVDR studies; Farmer et al., 2010). Laboratory research is typically more common however. This is because an experiment seeks to remove potential extraneous influences such that responses measured relate solely to the impact of manipulated conditions, often requiring the staging of an experimental scenario to mask the true purpose of the study (e.g. asking participants to ‘test-drive’ driving simulator equipment, when their natural speed choices are actually being recorded). Not all social psychological research includes laboratory or field-based experiments *per se* however. The hypothetico-deductive method can be used in other
research settings, including survey research for example, where data are gathered by asking participants to fill in questionnaires, or take part in an interview, in person, via telephone, or via the internet (e.g. Kervick et al., 2015).

In conducting these kind of studies, achieving sample representativeness, experimental realism, and control are essential considerations to ensure findings are as valid, and reliable, as possible. Representativeness refers to the need to make sure that the sample recruited to participate in a study (i.e. subjects or respondents) actually reflects the people the theory is proposed to be about (Breakwell, Smith, & Wright, 2016). An acknowledged limitation of many psychological studies is their heavy reliance on psychology undergraduate students as participants, who may not be optimally representative of the general population for example (Arnett, 2008; Henrich, Heine, & Norenzayan, 2010). Experimental realism then, relates to the ecological validity of the experiment, and to the extent to which the setting in which it is conducted and its design are close to ‘real life’. The use of high-fidelity driving simulators in road safety research is a good example of enhanced experimental realism (e.g. Klüver, Herrigel, Heinrich, Schöner, & Hecht, 2016; Li, Yan, Wu, Radwan, & Zhang, 2016; Sun, Ma, Li, & Niu, 2015).

Last, experimental control is essential to the hypothetico-deductive method, in that it can really only succeed if the researcher can isolate extraneous variables, control the manipulation of independent variables, and accurately measure dependent variables to provide true tests of the hypotheses proposed (Breakwell et al., 2016). These factors all need to be considered when designing a research study, and an optimal balance achieved between them all. Often, greater realism can mean less control for example, and representativeness, while an important factor to aim for, may result in time-consuming and expensive recruitment drives.

A2.2.4 Alternative approaches. Returning to the overarching research questions in Table 1 (above), it is again important to stress that each suggests the presence of either predictive or causal relationships - relationships that are ultimately further specified in directional hypotheses for each study. This high degree of specification in prediction requires a hypothetico-deductive approach rather than an approach that has a more phenomenological epistemology. Social Psychology and its associated methodological solutions, as described above, offers such an approach and thus has good fit with the overall research questions. This is not to say, of course, that other approaches either: 1) do not also offer hypothetico-deductive methodological solutions, or; 2) that alternative questions (e.g. more exploratory questions) could not have been posed to address other aspects of the phenomena related to
Other researchers within the broad field of psychology have examined the acceptance and use of novel devices using markedly different research designs and approaches. Research within the area of Human-Computer Interactions (HCI) for example, has focused on evaluating a new technology through conceptualising the person involved, the environment and tool as a holistic unit for analysis, to generate implications for design and distribution (e.g. González-Torres, García-Peñalvo, & Therón, 2013; Sharma & Verma, 2015). A number of theories, including distributed cognition (Hutchins, 2001), situated cognition (Brown, Collins, & Duguid, 1989), situated action (Suchman, 1987), and Cultural Historical Activity Theory (‘CHAT’; Engeström, 2008; Engeström & Sannino, 2012; Kuititi & Engeström, 2006; Vänninen, Pereira-Querol, & Engeström, 2015) would broadly advocate for this approach.

The study of distributed cognition for example, involves the in-depth examination of processes whereby cognitive resources are understood to be shared socially between humans and machines/technology, or between cognitive agents, to extend individual cognitive resources, or accomplish something an individual agent could not have achieved alone. Such achievements are based on a process in which an agent’s cognitive processes, the object(s), and constraints of the world/environment reciprocally impact on one another. Situated action (Suchman, 1987), then, aims to offer detailed accounts of how technology is used by people in different contexts (and how this is often not used as it was intended). It considers the study of humans interacting with technology to involve the provision of accounts ‘of relations among people, and between people and the historically and culturally constituted worlds that they inhabit’ (p. 71), achieving this through analysing ‘how people use their circumstances to achieve intelligent action’, while understanding that this is also shaped by their embodied and past experiences.

In order to examine technology acceptance and use in line with these kinds of approaches, qualitative (e.g. phenomenology, discourse analysis), ethnographic and ethnomethodological research methods have typically been employed. As a qualitative research approach, phenomenology involves the ‘thick description’ and in-depth analysis of lived experience, to understand how the meaning and common features, or essences, of an experience or event, is created through embodied perception (Starks & Brown-Trinidad, 2007). Discourse analysis has evolved from linguistic studies, semiotics, and literary criticism, and maintains that the detailed analysis of language (using the seven ‘building tasks’ of language, including: identities; connections; sign systems and knowledge for
example), can inform understanding on the creation and maintenance of social norms, the negotiation of political and social interactions, and the construction of group identities (Starks & Brown-Trinidad, 2007). Overall, phenomenological research, and discourse analysis, both seek to understand the subjective, lived experiences and perspectives of participants, providing the researcher with information regarding an individual’s unique experience as typically obtained through personal interview, or focus group work.

Ethnography, with its origins in anthropology, can be defined as both a qualitative research process (i.e. one conducts the ethnography) and product (the outcome of the process in an ethnography), whose core aim is cultural interpretation, including a core focus on the importance of the socio-environment context (for an overview, see Bannon, 1996). Ethnographers generate understanding of culture and experience through representation of the ‘emic’ perspective, or insider’s point of view, in which critical categories and meanings from unstructured data emerge from the ethnographic encounter (e.g. Garro, 1982; Nina, Anita, & Marja, 2012). Ethnography does not involve a single method, and can include direct observation, interviews, discourse analysis, diary techniques, and even surveys in naturalistic settings (typically workplace settings in the case of HCI).

Ethnomethodology, then, is concerned with how people accomplish social order in their everyday lives and work settings, maintaining the view that people shape their actions, rather than their actions being shaped by their environment. It is a ‘social inquiry, dedicated to explicating the ways in which collectivity members create and maintain a sense of order and intelligibility in social life’ (Have, 2004, p. 14). Within HCI, this has provided detailed, descriptive accounts of work practices through which actions and interactions are achieved, typically through naturalistic observations and the use of audio or video recording to facilitate conversation analysis (Button & Sharrock, 2009).

While such exploratory approaches and methodologies have much value when probing certain research topics and questions (they can generate richly detailed data on personal experiences and narratives for example), they do not provide optimal fit with the research questions posed in this research - which, as noted earlier, point towards predictive and causal relationships. This is not to say that qualitative research is ‘better’ or ‘worse’ than other methods, but rather that a core feature of best practice research is that the methods deployed have good ‘fit’ with the question being investigated. In this case, the research points primarily towards the hypothetico-deductive approach.
A2.3 The current research

The primary aim of the current programme of research is to evaluate SDSS use in a young driver context in the ROI. The research focuses on young drivers aged between 18-24 years, as studies suggest these are a particularly high-risk group, who may stand to benefit greatly from such technology, in both the immediate present and across their lifespan (Dogan et al., 2012; Simons-Morton et al., 2013). This young driver focus is also justified as insurance companies have typically targeted this driving demographic when advertising in-vehicle monitors for consumer use (Axa, 2016; McCartt & Teoh, 2015). Overall, this programme of research was conducted within three main sections: Section B - ‘Acceptance’, Section C - ‘Efficacy’, and Section D - ‘Distraction’. Section A provided a context to the research proposed, and Section E provides a comprehensive discussion of the overall findings of the thesis.

Section B - Acceptance

During Section B (‘Acceptance’), a systematic review of the young driver monitoring acceptability literature was first conducted (Study 1). The aim of this study was to establish a robust evidence base regarding the factors likely to influence SDSS acceptance (by reviewing the conceptually similar IVDR literature), and from which to inform subsequent acceptance empirical studies. As such, the primary research question guiding this analysis was:

1. What factors impact on young driver acceptance and adoption of in-vehicle monitoring technology?

Study 2 then, sought to build upon the foundation of evidence established in Study 1, and a review of the greater Technology Acceptance (TA) literature, to build and test a novel, structural model of young driver acceptance of SDSSs using Structural Equation Modeling (SEM). This study aimed to answer the following overarching question:

1. What factors, and broader model, predict young driver acceptance of a SDSS?

Overall, Section B (‘Acceptance’) strove to first, establish an evidence base and highlight the factors likely to influence young driver acceptance of SDSSs as identified by past research. This then informed the generation, and testing, of a young driver, SDSS-specific model of TA, which identified the influential factors significantly predicting young

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driver intentions to use SDSSs. These findings were then carried forward to aid in the design of the next section of the programme of research featured in this thesis.

Section C - Efficacy

Section C (‘Efficacy’), also commenced with a systematic review, which examined the young driver monitoring efficacy literature. The aim of this study (Study 3) was to systematically examine the effects of engaging with a personal, in-vehicle monitoring device on young driver behaviour, identify the theoretical mechanisms underlying this process, and build an evidence base from which to inform and design future SDSS efficacy studies. This analysis was guided by the following research questions:

1. Does monitoring of young drivers lead to a reduction in risky driving?
2. What are the Behaviour Change Techniques (BCTs) employed in these interventions?

Following this, and prior to assessing the impact of SDSS implementation on young driver behaviour, Studies 4a and 4b were conducted to evaluate the novel driving simulator obtained for the purpose of conducting the experimental SDSS studies. These studies sought to identify the period of adaptation required by young drivers to adjust to using the novel simulator equipment (Study 4a), and to ensure its ability to record valid and reliable driving outcomes (Study 4b), prior to conducting the empirical SDSS research informed by the findings of Study 3. These two sets of analyses were guided by the following research questions respectively:

1. What is the minimum adaptation period for young drivers to adjust to driving with the novel simulator equipment?
2. Does the driving behaviour observed in the simulator reflect valid, ‘real-world’ reported driving?

Building upon the findings of Studies 3, 4a and 4b, Study 5 then aimed to determine the impact of SDSS monitoring alone (i.e. without feedback) on young driver speed in a simulated environment. It also aimed to elucidate whether the theory of Self-Regulation (SR) could account for any changes in behaviour observed. A final aim of this study was to identify whether or not the overall relationship was influenced by a potential series of
individual difference variables, including trait SR, and fear of negative evaluation (FNE).

Three main research questions governed this study and analyses:

1. Does the implementation of SDSS monitoring improve young driver speed?
2. Are any observed speed changes due to SR?
3. Is the impact of SDSS monitoring on speed moderated by additional individual difference variables?

Having established that monitoring alone can influence young driver speed (Study 5), Study 6 aimed to evaluate a more complex SDSS, by assessing the impact of a SDSS providing real-time, visual SDSS feedback alerts, a monitoring SDSS offered in conjunction with a financial incentive, or a SDSS providing a combined financial incentive with real-time, visual feedback alerts on young driver speed. It also aimed to elucidate whether the theory of SR and/or operant conditioning (OC) could account for any changes in behaviour observed. Last, the final aim of this study was to identify whether or not the impact of a SDSS is influenced by a potential series of individual difference variables, such as trait SR, or extent of personal acceptance of SDSS monitoring. Three main research questions were utilised to guide the subsequent analyses:

1. Does the implementation of SDSS monitoring with either real-time visual feedback, a financial incentive, or both, improve young driver speed?
2. Are any observed speed changes due to SR and/or OC?
3. Is the impact of SDSS real-time visual feedback alerts, a financial incentive, or both, on speed moderated by additional individual difference variables?

Overall, Section C (‘Efficacy’) strove to first, establish an evidence base regarding the efficacy of young driver engagement with in-vehicle monitoring and feedback devices, and identify the potential theoretical mechanisms underlying this. Building from these findings, and an examination of the novel driving simulator obtained for the purpose of conducting SDSS empirical research, a series of SDSS experimental studies were carried out to elucidate the efficacy of varying SDSSs in a young driver use context. Results from these studies were then carried forward to inform the final empirical study of the programme of research featured in this thesis.
Section D - Distraction

Given the positive impact on young driver speed that SDSS implementation was observed to have (Study 5 and 6), but also the concerns voiced throughout Sections B and C regarding the potential for young driver distraction when engaging with real-time SDSS feedback, the final step in the evaluation of young driver SDSS use sought to examine driver distraction. This final empirical research study (Study 7) aimed to provide a preliminary, initial examination of this issue by examining whether receiving real-time, visual SDSS feedback could potentially result in young driver distraction, as measured primarily by performance on a concurrent peripheral detection task (PDT). This study was guided by the following overarching research question:

1. Does driving with real-time, visual SDSS feedback cause young driver distraction as evidenced by impaired PDT performance while driving?

Overall, Section D ('Distraction') strove to initiate the empirical examination of young driver distraction when engaging with in-vehicle monitoring devices (specifically, with an SDSS). It aimed to provide an initial indication as to whether SDSS use could result in distracted driving, and detrimental young driver outcomes, and inform future investigations of this issue.

Specific hypotheses relating to each of the studies in the different sections are presented in the relevant empirical chapter. The different studies conducted to evaluate young driver SDSS use are outlined below (Figure 2).
Figure 2. Empirical research sections, with listed component studies.
Section B - Acceptance: What factors influence young driver acceptance of SDSS technology?

Overview

This section seeks to examine the extent to which young people deem SDSSs as acceptable for use while driving, and what factors influence their willingness to adopt them. In order to achieve this, it first reports on the findings of a systematic review, which sought to establish an evidence base on the factors impacting on in-vehicle monitoring acceptance in the context of young driver usage (Section B1, Study 1). Building from the review findings, and a more general review of the greater Technology Acceptance (TA) literature, a novel structural model of young driver SDSS acceptance was then proposed and tested with a young driver sample (Section B2, Study 2). A summary of the findings stemming from this acceptance section is then provided (Section B3).

B1.1 Abstract

**Background:** In order for SDSSs to change behaviour, young drivers must first accept this technology and willingly adopt it for use. Published research in the area of driver monitoring has typically featured diverse methodologies and outcome measures, and little is known regarding what overarching factors influence this. As such, it is unclear as to what variables could be potentially targeted to increase young driver uptake of SDSSs.

**Aims:** The aim of this first study was to synthesise and establish a robust evidence base regarding the factors likely to influence SDSS acceptance and adoption, and from which to inform subsequent empirical studies in the current programme of research.

**Methodology:** A systematic review of the young driver IVDR acceptability literature was conducted. Five electronic databases were searched using specified key word combinations (e.g. ‘young driver’ and ‘in-vehicle data recorder’), and hand searches of academic journals were also completed. Narrative synthesis was employed to analyse the studies extracted.

**Findings:** Six studies (mixed methods, and of low quality) were extracted for narrative synthesis. The perceived accuracy and reliability of a monitor (‘perceived accuracy’), how easy it is to use (‘perceived usability’), the extent of potential risks and dangers associated with usage (‘perceived risks’), and potential benefits for the young driver (‘perceived gains’) emerged as key factors reported to influence young driver monitor acceptance and adoption.

**Conclusions:** Given the conceptual similarities between IVDR and SDSS technology, it is anticipated that these factors will also influence young driver SDSS adoption decisions, and technology acceptance. Certain unique characteristics are retained by SDSSs however (e.g. their greater potential to be circumvented), such that SDSS-specific investigations are warranted for definitive findings on this topic at this stage.

**Implications:** These findings suggest SDSSs will likely prove acceptable for young driver use, and provide evidence to inform the proposal of a SDSS-specific adoption and acceptance model to be tested in Study 2.
B1.2 Introduction

One of the conclusions from Section A was that the implementation of SDSSs represents a promising young driver intervention to address their heightened RTC rates. Despite this, little is known regarding how acceptable for use young drivers deem SDSSs, and by extension, if they will actually be adopted in the first place. This chapter presents a systematic review of the young driver, in-vehicle monitoring acceptability, research literature. In the absence of SDSS-specific research, the central objective of this study was to provide an up-to-date review elucidating the factors likely to impact upon young driver SDSS acceptance (i.e. the acceptability of the technology), by reviewing the conceptually similar IVDR literature pertaining to this age group and research question. This will inform the design and generation of a SDSS-specific model of TA, to be later tested with a young driver sample (Section B.2, Study 2).

B1.3 Concepts: Acceptance and acceptability

Throughout the greater TA and adoption literature, there has been a noted degree of conceptual ambiguity surrounding the terminology used in this field, with researchers using terms such as ‘acceptance’, ‘acceptability’, ‘willingness to use’ or ‘usability’, interchangeably (see Regan, Horberry, & Stevens, 2014 for an overview). To clarify, here, positive (or negative) judgements and perceptions of the technology in question are defined as referring to device acceptability. Occasionally referred to as ‘attitudinal acceptance’, acceptability relates to ‘how much a system is liked’ (Jamson, 2010, p. 15), and is a ‘prospective judgement’ of a novel system based on little experience (Schade & Schlag, 2003, p. 47), and can be regarded as a pre-cursor to acceptance and adoption. Acceptance then, refers to a willingness and intent to adopt and use the technology - a ‘behavioural intention’, which has been found to predict actual technology adoption behaviour (see Venkatesh, Morris, Davis, & Davis, 2003 for review). It is ‘the degree to which an individual incorporates the system in his/her driving, or, if the system is not available, intends to use it’ (Adell, 2009, p. 31). This is, of course, distinct from the act of uptake for use itself, which is referred to as technology adoption. Thus, for the purpose of the current systematic review, the term ‘acceptance’ is used to refer to an individual’s expressed willingness or intention to adopt or purchase the technology in question. The ‘acceptability’ of this technology then denotes the expressed attitudes and value-related young driver judgements or perceptions identified as influencing willingness and intention to use, which were the focus of this systematic search, and overall review question.
**B1.4 Theoretical models of Technology Acceptance**

Prior to completing the systematic review, a brief literature review of the broader TA literature was conducted, to provide a historical context and introduction to the topic of TA, and an indication of the model structures and likely factors to emerge when examining the young driver monitoring acceptability literature. In all, TA research spans decades of academic studies and work, has featured multiple proposed explanatory models and theories, and traverses the fields of information systems, psychology and sociology (Gücin & Berk, 2015; Peek et al., 2014; Venkatesh et al., 2003). Although a multitude of models exist, this preliminary review of the greater TA literature suggested that the predominant theories and models that have had the greatest impact in published research are, broadly speaking, the Theory of Reasoned Action (‘TRA’; Fishbein & Azjen, 1975), Theory of Planned Behaviour (‘TPB’; Ajzen, 1991), Technology Acceptance Model (‘TAM’; Davis, 1989), and the Unified Theory of Acceptance and Use of Technology (‘UTAUT’; Venkatesh et al., 2003). Such models and theories have been applied and/or adapted to both mandatory (e.g. in the context of employment) and personal voluntary TA and adoption (e.g. see C.-D. Chen, Fan, & Farn, 2007; Ovčjak, Heričko, & Polančič, 2015; Park, Rhoads, Hou, & Lee, 2014; Venkatesh et al., 2003) and may be relevant in a SDSS context.

In looking first to the TRA, the main premise of this theory and model is that the target behaviour (in this case, adopting a novel technology) and intention to perform this, is determined by an individual’s attitude(s) towards the technology in question and related perceived subjective norms. Such attitudes are ‘an individual’s positive or negative feelings towards performing the target behaviour’ (Fishbein & Azjen, 1975, p. 216), whereas subjective norms refer to ‘the person’s perception that most people who are important to him think he should or should not perform the behaviour in question’ (Fishbein & Azjen, 1975, p. 302). This model has been successfully used in the context of predicting acceptance and/or adoption of an array of diverse technologies, such as livestock management devices, to Green Information Technology (Liker & Sindi, 1997; Mishra, Akman, & Mishra, 2014; Rehman et al., 2007). This was then extended to become the TPB, through the addition of a perceived behavioural control variable, referring to the ‘perceived ease or difficulty of performing the behaviour’ (Ajzen, 1991, p. 188), and which, in the context of TA research, could then be used to predict both intention to use and adoption behaviour. This theory and model has also been applied and studied extensively in relation to the acceptance and/or adoption of a multitude of technologies, such as using online video services (Truong, 2009), educational
resources for teachers (J. D. Lee, Cerreto, & Lee, 2010), adolescent social network usage (R. K. Baker & White, 2010), or online shopping (Herrero Crespo & Rodríguez del Bosque, 2008).

Drawing from the TRA and TPB, the TAM then strove to introduce a more parsimonious model of TA, proposing that users come to accept and use technology based primarily on both its perceived ease of use, and perceived usefulness (Davis, 1989; Davis & Venkatesh, 1996). Perceived ease of use was defined as the ‘degree to which a particular person believes that using a particular system would be free of effort’ (Davis, 1989, p. 320), with clear links to the previous perceived behavioural control variable from the TPB. Perceived usefulness then refers to ‘the degree to which a person believes that using a particular system would enhance his or her job performance’ (Davis, 1989, p. 320), broadly relating to the attitudes and social norms variables from the TRA and TPB. Prior to the design of the UTAUT, the TAM was regarded as the most widely used theory and model of TA within the information systems discipline (Venkatesh et al., 2003; M. D. Williams, Dwivedi, Lal, & Schwarz; 2009), being used to study acceptance of numerous technologies (e.g. see King & He, 2006 for review), such as software measurement tools (Wallace & Sheetz, 2014), to mobile banking (Munir, Idrus, Kadir, & Jusni, 2013).

Many of these theories have since been extended (TAM 2 incorporated the subjective norm variable from the TRA/TPB for example; Venkatesh & Davis, 2000; Wu, Chou, Weng, & Huang, 2011) or even combined (e.g. the combined TAM and TPB; the C-TAM-TPB, included TPB variables with the perceived usefulness TAM variable to produce a hybrid predictive model; S. Taylor & Todd, 1995), to adapt to different TA demands and contexts (Schepers & Wetzels, 2007). Most typically explain up to 40% of outcome variance in any given TA study (e.g. see Sun & Zhang, 2004; Venkatesh et al., 2003), and have been found to predict TA across an array of devices, and/or technological systems.

The UTAUT (Venkatesh et al., 2003) then, is the most recently proposed, dominant model of TA, which aimed to synthesise this extensive body of research and number of theoretical models to produce an all-encompassing, definitive, predictive TA model. It did so by reviewing, mapping and integrating eight of the prevalent theories and models within this field, namely the TRA, TPB, TAM, the Motivation Model (MM), C-TAM-TPB, Model of PC Utilisation (MPCU), Innovation Diffusion Theory (IDT) and Social Cognitive Theory (SCT). This approach was adopted as many of the constructs of existing theories are similar in nature, and as such, it would be logical to integrate them and create a unified theoretical base for TA researchers to use going forward (Tan, 2013). This theory proposed that four central
constructs, including performance expectancy (‘the degree to which an individual believes that using the system will help him or her to attain gains in job performance’, p. 447), effort expectancy (‘the degree of ease associated with the use of the system’, p. 450), social influence (‘the degree to which an individual perceives that important others believe he or she should use the new system’, p. 451), and facilitating conditions (‘the degree to which an individual believes that an organisational and technical infrastructure exists to support use of the system’, p. 453) are direct determinants of intention to use a novel technology, and ultimately, adoption and usage behaviour (Venkatesh et al., 2003). The effects of these core constructs are also assumed to be moderated by age, gender, experience and voluntariness of use. The original model test of the UTAUT was found to account for 70% of outcome variance, substantially out-performing the majority of previous TA models (Venkatesh et al., 2003). A UTAUT-2 has also since been proposed (incorporating additional factors such as price value to account for acceptance in a consumer context), and is purported to account for similarly high levels of outcome variance (Harsono & Suryana, 2014; Venkatesh, Thong, & Xu, 2012).

This theory is not without criticism however. Other researchers have employed the UTAUT model and reported that it accounts for far lower outcome variance than originally stated (e.g. 63.1%, Al-Gahtani, Hubona, & Wang, 2007, 35.3% without interactions, and 39.1% with interactions; Teo, 2011). In addition, although the reliability and validity of the model has been confirmed (Al-Gahtani et al., 2007; Nassuora, 2012; Wang & Shih, 2009) consensus on the proposed relationships between the factors has not always been achieved, with a number of inconsistencies reported. Some have reported a significant positive effect of performance expectancy on behavioural intention (BI) to use, for example (e.g. Im, Hong, & Kang, 2011), whereas others do not (Jairak, Praneetpolgrang, & Mekhabunchakij, 2009). These reported inconsistencies in explanatory power and relationships between the UTAUT variables have been attributed in part to the need for TA models to be context-specific (e.g. T. D. Thomas, Singh, & Gaffar, 2013). In line with this, a unique recent analysis provided by M. D. Williams, Rana, Dwivedi, and Lal (2011) has identified that although the UTAUT is widely cited, relatively few studies have used the original UTAUT model in TA research, preferring to adapt this for the purpose of the study of the particular technology they are testing, and adding variables to the original UTAUT constructs.

The majority of recently published TA studies have adopted this tailoring approach, wherein constructs are drawn from existing, established models and incorporated into an adapted or novel technology/context-specific TA model (e.g. Ariff, Yeow, Zakuan, Jusoh, &
Given such findings and that to date, no empirical TA research has examined the factors influencing acceptance and/or adoption of novel SDSSs, within the unique context of their user groups etc., this approach will also likely need to be employed in conceptualising young driver SDSS acceptance and adoption. As such, for the purpose of this systematic review, an emphasis was placed on identifying potentially relevant and predictive factors of young driver acceptance and adoption, rather than searching for specific components of overarching TA theories.

**B1.5 Rationale for the current study**

SDSSs represent an innovative, cost-effective monitoring alternative for young drivers, with the potential to improve driving-related outcomes for this vulnerable driving group (Creaser et al., 2011; Creaser et al., 2009). Acceptance of such novel technology is of key importance, and particularly so in the context of voluntary usage. Studying the efficacy of SDSSs in a young driver population is purely an academic pursuit if young people are unwilling to adopt and use them in the ‘real world’. Understanding the acceptability of this kind of technology to young drivers can also identify means to maximise future uptake levels (e.g. by targeting factors revealed to increase acceptance and adoption likelihood) and increase any potential protective benefits of SDSS use. In the absence of a substantial body of SDSS research, systematically reviewing the conceptually similar IVDR literature serves as the most empirically sound means to amass evidence to inform thinking on SDSS acceptability, that can be used to design future models to predict SDSS acceptance and adoption rates (Chapter 4 - Section B2).

Thus, this chapter presents the findings of the first systematic review of the young driver monitoring literature. This review focused specifically on the acceptability of driver monitoring technology to young drivers, and sought to answer the following question: ‘What factors impact on young driver acceptance and adoption of in-vehicle monitoring technology?’ Having addressed this review question, this chapter concludes by considering the implications of the findings in light of young driver acceptance and adoption of SDSS technology.
B1.6 Method

Systematic search procedure

In-vehicle monitoring technology, as with all forms of technology, is evolving rapidly (Auricht & Stark, 2014; Michalke, Gußner, Bürkle, & Niewels, 2014). In order to ensure the inclusion of relevant research in the review, only articles published over 10 years from 2003-2013 were selected for synthesis. A comprehensive search of 5 online databases was conducted (ScienceDirect, Scopus, PsycINFO, Transport Research International Documentation [TRID] and Web of Knowledge). A series of key search terms pertaining to the review question were generated, and selected for inclusion following a series of provisional scoping searches. Acceptability-related words such as ‘acceptance’ or ‘usability’; monitoring specific phrases including ‘in-vehicle data recorder’ and; population specific terms such as ‘young driver’ or ‘teen driver’ were entered.

These terms were typically combined using the operands AND/OR (depending on the search engines being utilised). Hand searches of issues of Accident Analysis and Prevention, the Journal of Safety Research, Transportation Research Part F and Safety Science from 2003-2013 were also later carried out, as the majority of articles identified from the electronic searches were published in these. The references sections from each paper selected for inclusion in the review were also examined for potentially relevant material. Last, a number of key researchers within the area were contacted with requests for any in-press or recently submitted research that could be potentially considered for inclusion, in order to access literature recently accepted for publication.

Inclusion and exclusion criteria

Reflecting the exploratory nature of the review question, the inclusion and exclusion criteria for this systematic review were deliberately broad. To be included in the review, research had to feature young driver participants (male and/or female under 25 years of age), and be published in English, between the years 2003-2013 inclusive. In addition, the research had to probe perceptions, attitudes and/or beliefs in relation to using an in-vehicle monitoring device (i.e. acceptability) as the primary focus of the data collected.

Data extraction and synthesis

An Endnote database was created to store the identified studies for assessment (total \(n = 1,194\)). First, duplicate articles were removed (\(n = 673\) remaining). Study titles were then screened for relevance to the review question (\(n = 48\) remaining). Abstracts were then assessed to ensure the inclusion criteria were met (\(n = 20\) remaining). Last, full texts of these
articles were accessed and examined to ensure the appropriate inclusion of the final group of studies to be included in the review (final n = 6) (see Figure 3 for the Preferred Reporting for Items for Systematic Reviews and Meta-Analyses [PRISMA] Chart; Moher, Liberati, Tetzlaff, & Altman, 2009). Results presented here are based on the analysis of these six studies.

The studies obtained to answer the review question were primarily qualitative or mixed methods (see Table 1), and thus a narrative synthesis of the research findings was conducted. Study quality was assessed using an adapted checklist from the National Institute for Health and Clinical Excellence Guidelines Manual ('NICE', 2007), which draws from the Critical Appraisal Skills Programme (CASP), and the work of Bromley et al. (2003) (see Table 2). The majority of the studies reviewed were of relatively low quality (e.g., few employed rigorous data analyses, or gave consideration to the ethical issues associated with their research), however it was decided not to exclude any of the final studies identified on the basis of this, to ensure sufficient review material. Rather, the results of the review were interpreted in light of these issues. Guidance for narrative synthesis was taken primarily from Popay et al. (2006) and J. Thomas and Harden (2008), and relevant data were tabulated into an extraction table (Table 1) to facilitate this process. The author completed this process, under the supervision of the two project supervisors (KS and DOH).
Records identified through database searching (n = 1192)

Additional records identified through other sources (n = 2)

Records after duplicates removed (n = 673)

Titles screened (n = 673)

Records excluded (n = 625)

Abstracts screened (n = 48)

Records excluded: 28
  Ineligible participant group (n = 4)
  Not monitoring related (n = 2)
  Not acceptability related (n = 22)

Full-text articles assessed for eligibility (n = 20)

Records excluded: 14
  Ineligible participant group (n = 10)
  Not acceptability related (n = 4)

Studies included in narrative synthesis (n = 6)

Figure 3. PRISMA diagram outlining study selection procedures.
Table 2
*Extracted acceptability studies from a systematic review of the young driver monitoring literature.*

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td>To conduct a usability evaluation of a pilot smartphone Teen Driver Support System.</td>
<td>To examine young driver perceptions of in-vehicle monitoring versus parental accompaniment.</td>
<td>To examine young driver and parental perceptions of IVDR use and the implications for their relationship.</td>
<td>To assess the perceptions and experiences of participants in a monitoring study.</td>
<td>To systematically identify and structure the range of alternatives that might use vehicle based sensing to mitigate the novice teen driver safety problem.</td>
<td>To examine the acceptability of different IVDR system components to young rural and urban Australian drivers.</td>
<td></td>
</tr>
</tbody>
</table>
| **Sample Characteristics**

<table>
<thead>
<tr>
<th>N = 60 (30 Teens, 30 Parents)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young M (n = 14)</td>
</tr>
<tr>
<td>Mean Age: 17.68</td>
</tr>
<tr>
<td>Young F (n = 16)</td>
</tr>
<tr>
<td>Mean Age: 17.49</td>
</tr>
<tr>
<td>Father (n = 4)</td>
</tr>
<tr>
<td>Mean Age: 54.5</td>
</tr>
<tr>
<td>Mother (n = 26)</td>
</tr>
<tr>
<td>Mean Age: 48.2</td>
</tr>
<tr>
<td><strong>N = 137</strong></td>
</tr>
<tr>
<td>67 M, 70 F</td>
</tr>
<tr>
<td>Age range: 16-17</td>
</tr>
<tr>
<td><strong>N = 79</strong> (39 families in total)</td>
</tr>
<tr>
<td>Home interviews:</td>
</tr>
<tr>
<td>22 parents (12 M, 10 F).</td>
</tr>
</tbody>
</table>
| 14 young drivers **
| Phone interviews: |
| 21 parents (10 M, 11 F) |
| 12 young drivers (9 M, 3 F)* |
| **N = 83 parent/teen dyads** |
| Teens (54% F, 46% M). |
| Parents (70% F, 30% M)* |
| **N = 48** |
| Group 1: 8 parents where child will be first licensed, 8 drivers under the age of 18 with learners permit or licence. |
| Group 2: 10 parents where child has licensed older siblings, 10 drivers under the age of 18 with learner permits or licence. |
| Group 3: 6 parents whose child had been in a crash/been cited for a driving offense, 6 drivers with full licence not under 18 ** |
| **N = 58** |
| Sydney Participants: |
| n = 38 (6 F, 32 M) |
| Mean Age: 20.55 |
| Wagga Wagga Participants: |
| n = 20 (3 F, 17 M) |
| Mean Age: 19.8 |

| **Design Description**

<table>
<thead>
<tr>
<th>Participants completed a demographic, driver behaviour and usability survey.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Personal interviews with 26 teens who had driven with a monitor, and 11 additional focus group interviews were conducted.</td>
</tr>
<tr>
<td>Home interviews and phone surveys were conducted.</td>
</tr>
<tr>
<td>Structured interviews.</td>
</tr>
<tr>
<td>Structured focus group interviews.</td>
</tr>
<tr>
<td>8 separate young driver focus groups were conducted, 4 included participants from rural Wagga Wagga and 4 from Sydney.</td>
</tr>
<tr>
<td>Analytical Themes</td>
</tr>
<tr>
<td>-------------------</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type of Monitor</th>
<th>Teens evaluated 7 functions: a seat belt reminder, passenger presence reminder, advance speed notifications, speed limit warnings, curve speed warnings, stop sign violations and excessive manoeuvre warnings.</th>
<th>IVDR</th>
<th>IVDR</th>
<th>4 systems assessed: System 1: Video monitor with in-vehicle alerts and post-journey parental and professional coaching feedback. System 2: Monitor which provides real-time audio feedback and limited post-journey information. System 3: Monitor with vehicle tracking which notifies parents in real-time of violations. System 4: Monitor without real-time alerts, which sends weekly reports to parents.</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>USA</th>
<th>Israel</th>
<th>Israel</th>
<th>USA</th>
<th>USA</th>
<th>Australia</th>
</tr>
</thead>
</table>

* Age not available; ** Age, gender not available.
Table 3
Quality assessment of extracted acceptability studies.

<table>
<thead>
<tr>
<th>Study</th>
<th>Aims and objectives clearly stated?</th>
<th>Qualitative approach appropriate?</th>
<th>Research question(s) clearly defined and focused?</th>
<th>Methods used appropriate?</th>
<th>Recruitment strategy appropriate?</th>
<th>Data collection methodology adequate?</th>
<th>Role of researcher clearly described?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creaser et al. (2011)</td>
<td>Unclear</td>
<td>N/A - survey based</td>
<td>Unclear</td>
<td>Unclear</td>
<td>Appropriate</td>
<td>Adequate</td>
<td>N/A</td>
</tr>
<tr>
<td>Gesser-Edelsburg &amp; Guttman (2013)</td>
<td>Clearly described</td>
<td>Appropriate</td>
<td>Not defined</td>
<td>Unclear</td>
<td>Appropriate</td>
<td>Adequate</td>
<td>Not reported</td>
</tr>
<tr>
<td>Guttman &amp; Gesser-Edelsburg (2011)</td>
<td>Clearly described</td>
<td>Appropriate</td>
<td>Unclear</td>
<td>Unclear</td>
<td>Appropriate</td>
<td>Adequate</td>
<td>Not reported</td>
</tr>
<tr>
<td>McCartt et al. (2010)</td>
<td>Clearly described</td>
<td>N/A - survey based</td>
<td>Unclear</td>
<td>Unclear</td>
<td>Appropriate</td>
<td>Adequate</td>
<td>N/A</td>
</tr>
<tr>
<td>Lerner et al. (2010)</td>
<td>Unclear</td>
<td>Appropriate</td>
<td>Unclear</td>
<td>Unclear</td>
<td>Unclear</td>
<td>Not reported</td>
<td>Not reported</td>
</tr>
<tr>
<td>K. L. Young et al. (2003b)</td>
<td>Clearly described</td>
<td>Appropriate</td>
<td>Unclear</td>
<td>Unclear</td>
<td>Appropriate</td>
<td>Adequate</td>
<td>Not reported</td>
</tr>
</tbody>
</table>
### Table 2

**Quality assessment of extracted acceptability studies (contd.).**

*Note: ‘++’ = all or most criteria have been fulfilled, ‘+’ = some of the criteria have been fulfilled, ‘-’ = few or no criteria have been fulfilled.*

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>Creaser et al. (2011)</td>
<td>Not adequate</td>
<td>Rigorous</td>
<td>Valid – objective measurement</td>
<td>Limited relevance</td>
<td>Unclear</td>
<td>Not reported</td>
<td>-</td>
</tr>
<tr>
<td>Gesser-Edelsburg &amp; Guttman (2013)</td>
<td>Not adequate</td>
<td>Not rigorous</td>
<td>Unclear</td>
<td>Limited relevance</td>
<td>Clearly reported</td>
<td>Adequate</td>
<td>+</td>
</tr>
<tr>
<td>Guttman &amp; Gesser-Edelsburg (2011)</td>
<td>Not adequate</td>
<td>Not rigorous</td>
<td>Unclear</td>
<td>Relevant</td>
<td>Clearly reported</td>
<td>Adequate</td>
<td>+</td>
</tr>
<tr>
<td>McCartt et al. (2010)</td>
<td>Adequate</td>
<td>Rigorous</td>
<td>Valid – objective measurement</td>
<td>Limited relevance</td>
<td>Unclear</td>
<td>Adequate</td>
<td>+</td>
</tr>
<tr>
<td>Lerner et al. (2010)</td>
<td>Not adequate</td>
<td>Not rigorous</td>
<td>Unclear</td>
<td>Limited relevance</td>
<td>Unclear</td>
<td>Not reported</td>
<td>-</td>
</tr>
<tr>
<td>K. L. Young et al. (2003b)</td>
<td>Adequate</td>
<td>Not rigorous</td>
<td>Unclear</td>
<td>Relevant</td>
<td>Clearly reported</td>
<td>Adequate</td>
<td>+</td>
</tr>
</tbody>
</table>
B1.7 Results

Four primary factors (or ‘analytical themes’) identified as impacting upon monitor acceptance were extracted from the literature. These were ‘perceived accuracy’, ‘perceived usability’, ‘perceived gains’ and ‘perceived risks’.

Perceived accuracy

All of the six studies reviewed reported findings that suggest that young drivers’ willingness to adopt monitoring technology is influenced by the perceived accuracy or reliability of the device in question (see Table 1, Studies a-f). Two key issues influencing accuracy perceptions and thus, acceptance, of in-vehicle monitors were identified from the reviewed literature. First, a number of participants expressed concern that technological limitations of the devices could lead to unreliable feedback alerts. Second, young drivers have suggested that this technology is vulnerable to tampering by those being monitored. Both of these could negatively influence adoption likelihood.

K. L. Young et al. (2003b), for example, recruited 58, monitor-naïve participants aged 17-25 from rural or urban areas in New South Wales (Table 1, Study f). In evaluating seven different features of a prospective driver monitor (e.g. a forward collision warning component, lane departure warning component etc.) the reliability of each of these technologies emerged as an important factor influencing willingness to adopt a monitor for every feature examined. Comments from participants included: “It would have to be 100% reliable” (p. 68) and; “You would just have to disconnect it, if it wasn’t 100% reliable” (p. 68). Accordingly, monitor features perceived as being prone to inaccuracies, such as providing false alarms (i.e. inaccurately registering an unsafe driving event), or failures to detect unsafe stimuli were not perceived as acceptable for use. They were identified as a potential source of driver danger and annoyance, and as causing a loss of confidence with the system overall as “They could malfunction - they could go off all the time, or they could do the opposite and not go off at all and you are relying on it” (p. 68). Over-reliance on a system that may not be accurate was also a commonly voiced concern (e.g. Lerner et al., 2010; K. L. Young et al., 2003b).

In line with this, McCartt et al. (2010, see Study d, Table 1) reported on a series of interviews with 83 young drivers and their parents following their participation in an IVDR Randomised Control Trial (RCT) in the United States (Farmer et al., 2010). Young drivers frequently reported receiving what they perceived to be ‘undeserved’, inaccurate alerts when in receipt of real-time, in-vehicle feedback. Similar findings have been reported in
other young driver field studies (Guttman & Gesser-Edelsburg, 2011; Study c Table 1, and Gesser-Edelsburg & Guttman, 2013; Study b, Table 1). Drivers in the McCartt study also reported significantly less satisfaction with the monitoring system overall following their periods of monitored driving than other driving groups who did not receive in-vehicle alerts, reporting that such alerts were ‘annoying’, and which likely negatively impacted upon their willingness to use an IVDR again in future.

Last, young drivers have also suggested that they, or others, could easily ‘fool’ or cheat a driver monitoring system, which could result in undue benefits or rewards being distributed. Participants in the K. L. Young et al., (2003b) study, for example, suggested that a young driver could “[p]ut aluminium foil over the radar or cut a few wires”, as “It could be easily tampered with, and there would be a commercial incentive to design a way to tamper with the technology” (p. 70). A number of participants in Guttman & Gesser-Edelsburgs’ (2011) research reported tampering with the monitors, and the McCartt et al. (2010) study documented ways in which participants in their study tampered with the devices (e.g. by severing IVDR cables). In all, a device’s potential to be circumvented was typically seen by young driver participants as negatively influencing their willingness to use an in-vehicle monitor, such that devices would have to have “mechanisms so that people just can’t go and mess with the wires” (K. L. Young et al., 2003b, p. 102) in order to be acceptable.

Perceived usability

The ‘usability’ of a monitor can refer to the ease with which a device can be initially acquired, installed and then used and maintained by the driver over time. Ultimately, any factor that undermines the perceived usability (i.e. the perception of how easy it is to adopt/use) of a technology decreases acceptance and likelihood of actual usage (Bhattacherjee & Hikmet, 2008; T. W. Dillon & Lending, 2010). Within the literature, three perceived usability sub-themes identified as impacting upon a decision to adopt and drive with a monitor (or not) emerged: the financial cost of monitors and monitoring; skill requirements for using the technology, including obtaining online feedback, and; any practical, physical, barriers to their installation and use.

In terms of costs, monitoring can involve both financial outlay and gain. In-vehicle data recorders can cost several hundred euro to purchase, install and maintain, and as such it is perhaps unsurprising that the expense associated with this technology was highlighted as central to the decision of young drivers and parents to adopt/reject a monitor throughout the reviewed studies. Participants in the K. L. Young et al. study (2003b) claimed that cost was
“… a big one” (p.70) and that “Price definitely” (p. 71) was a significant barrier to adoption and use for example. Young drivers in three teen/parent focus groups (total n = 48) in the United States conducted by Lerner et al. (2010, see Study e, Table 1) suggested that the cost of driver monitoring was prohibitive, and that their parents would not be interested in purchasing a device unless it was inexpensive. The attraction of potential financial benefits, such as reduced speeding fines and insurance premiums, have been acknowledged by participants (e.g. K. L. Young et al., 2003b), but there was a sense that drivers were interested in a risk/gains ratio. A monitoring device could potentially be worth “More than their car” and “You would not put it in there unless you got massive reductions on your insurance premium” (p. 64) for example. Continuous maintenance costs and future repairs were also voiced as serious concerns, and that some drivers “might find it cheaper to get it disconnected if it breaks, than to get it fixed” (p. 97). Cost is clearly an important factor for young drivers and/or their parents to consider before adopting an in-vehicle monitor.

Being able to obtain feedback via the internet to greater understand their driving was identified by some young drivers as an important and positive aspect of overall perceived usability (Guttman & Gesser-Edelsburg, 2011). While it might be expected that most young drivers have a high degree of technological self-efficacy, the literature would suggest that certain tasks, such as updating digital speed maps on the IVDR and accessing on-line feedback, may prove challenging for some (e.g. Lerner et al., 2010; K. L. Young et al., 2003b). Of note, parents, who may be involved in the monitoring process, can also struggle to access and interpret the report data presented (Lerner et al., 2010). Parents in Farmer et al.’s (2010) monitoring RCT, for example, did not adequately engage with the feedback reports website. In the continuation study by McCartt et al. (2010), parents reported that they found the online system hosting the feedback cumbersome to use, and the reports generated by the site difficult to interpret. It would appear that this undermined the overall acceptability and acceptance of the system, as was reflected by their low ‘log-in’ or usage rates. This is particularly relevant as parents’ acceptance and engagement with the monitoring technology and process has been identified as an influential factor in the success of driver monitoring (e.g. Farmer et al., 2010; Simons-Morton et al., 2013).

A final consideration relating to the perceived usability and acceptability of a young driver monitoring system is the physical requirements involved. A number of factors relating to the physical demands of driving with an IVDR were voiced by participants in McCartt et al.’s 2010 study. Their IVDR had to be installed by specialist technicians at what were described as ‘remote’ locations, reported as an ‘inconvenience’ for participants. There were a
number of technical problems with the devices administered, which required participants to return to this same remote location for repairs and maintenance. Similar concerns were noted in the K. L. Young et al. (2003b) study such as “How is your average mechanic going to fix the system..?” and that the “number of services it needs could be a problem” (p. 68) all of which undermine perceived usability.

Perceived gains

Despite potential issues surrounding accuracy and perceived usability, it is clear that some young drivers do accept and choose to adopt monitoring technology. Here some of the factors highlighted as enhancing technology acceptance in the studies included in the review are considered. Three sub-themes emerged: a belief that the system can enhance driving skills and safety; that the feedback can lead to praise and otherwise enhance the sense of self-worth of the driver; and that monitoring can have a financial benefit.

Young drivers have expressed an appreciation that in-vehicle monitoring can improve their driving skills and overall safety on the roads. Twenty-six young drivers in a qualitative study by Guttman & Gesser-Edelsburg’s (2011) were interviewed along with their parents via phone or at home following a period of IVDR use, and were found to view in-vehicle monitors as a tool to improve their driving skills, as a way to “see how you can improve and be more careful” (p. 53). It allowed them to focus on improving particular manoeuvres they had difficulties with, such as “how to moderate my turns” (p. 53). Participants with a monitor “really try to drive according to the rules... drive more carefully...” (p. 53) even to the extent that usage negates risky peer influences “they asked me to drive faster, but I told them I cannot because I have the squealer [monitor]” (p. 53). A total of 78% of drivers in McCartt et al.’s study (2010) said they believed monitor usage reduced their speeding, two thirds of those with in-vehicle alerts said the system made them better and safer drivers, and half reported that it helped and encouraged them to drive within the speed limits. Likewise, following a 30-minute test drive with in-vehicle alerts in place, the majority of participants in the Creaser et al. (2011) Teen Driver Support System (TDSS) study (see Study a, Table 1) reported that a smartphone-based monitor made them feel safer and more confident when driving. Eighty-three per cent also believed it positively changed the way they drove.

It would also appear that young drivers value the objective feedback that is provided by these systems. Gesser-Edelsburg & Guttman (2013) conducted a series of focus group interviews with 137 teen drivers, examining their perceptions of in-vehicle monitoring versus parental accompaniment while driving. Here, the benefits of objective feedback to provide evidence that a “young driver is a good one” above “subjective” assessments of parents was
acknowledged (p.119). Such feedback can also be valued for providing “a lot of positive reinforcement. My mother would check the feedback and see that I drove well, and kept telling me, ‘good going!’” (Guttman & Gesser-Edelsburg, 2011, p. 55). It may be the case that this feedback can promote constructive communication between a young driver and their parents, mitigating a potentially contentious time in their relationship. It may also be the case that drivers value the positive reinforcement that results when they are praised or otherwise rewarded for rule-adherence, and that this becomes a motivation for on-going use. For example, one participant reported that “It’s fun to get a good report about things you do… it does cause you to want to drive better” (Guttman & Gesser-Edelsburg, 2011, p. 53).

While the impact of perceived financial rewards was briefly discussed in relation to perceived monitor usability, it is worth noting that there is evidence that young people view the potential financial benefits of monitoring as an influential gain in their decision to adopt or reject a device (e.g. Lerner et al., 2010; K. L. Young et al., 2003b). In evaluating the number of different in-vehicle system components presented to them, the participants in K. L. Young et al.’s (2003b) focus groups consistently stated that insurance subsidies would improve their overall acceptance of the device, and that even the most undesirable components were evaluated more favourably when the potential to receive financial benefits was an option. Likewise, participants from the Lerner et al. focus groups (2010) claimed, for example, that they “wouldn’t mind obeying the rules making sure that the system didn’t go off to be able to get lower insurance rates” (p. 30).

Perceived risks

The research has also identified a range of perceived risks or potential barriers to driver monitoring, many of which are counterparts to the gains identified earlier. While monitoring can have a positive impact on driver-parent relationships, for example, there is a risk that negative feedback can also lead to conflict (e.g. see Creaser et al., 2011; Guttman & Gesser-Edelsburg, 2011). Similarly, while monitoring can improve driving, some drivers have reported a fear that any systems that actively intervene with driving could actually contribute to a collision (e.g. K. L. Young et al., 2010; Lerner et al., 2010; Lerner et al, 2010; K. L. Young et al., 2003b).

Three perceived potential risks associated with monitor usage emerged from the reviewing process. First, there was an understandable perception among drivers that the process of monitoring could result in an undesirable, and thus, unacceptable, loss of privacy (e.g. Gesser-Edelsburg & Guttman, 2013; K. L. Young et al., 2003b). In a number of studies, participants have used terms such as ‘squealer,’ ‘spy,’ ‘big brother’, a ‘stalking
system’ or even a ‘baby monitor’ for parents or insurers when discussing these devices (Guttman & Gesser-Edelsburg, 2011; Lerner et al., 2010). Although not all young drivers have reported this, for example one participant stated “I do not feel that it is a bother, because I always tell my parents where I am going, and do not have deep secrets from them” (Guttman & Gesser-Edelsburg, 2011, p. 56), the issue of privacy and security of personal driving data when using a monitor clearly is a significant concern impacting upon overall device acceptance.

Second, young drivers have expressed concern that IVDRs which actively intervene with the vehicle such that, for example, a vehicle’s speed will be reduced if it rises above a predetermined point (Intelligent Speed Adaptation, or ‘ISA’, e.g. K. L. Young et al., 2010), involve a loss of personal control over their vehicle that may be unsafe. “Sometimes it could be dangerous if you need to accelerate out of danger” (K. L. Young et al., 2003b, p. 60) or “shock you too much if it braked automatically” (p. 72). Participants have voiced preferences for the denouncement of such systems as “I don’t like the idea of the system having control of your brakes”, or at least for ‘over-ride’ functions to be present at all times, allowing them to retain control of their vehicle and rendering the use of a monitor more acceptable to them (Lerner et al., 2010; K. L. Young et al., 2003b, p. 67). Although not as relevant in considering SDSS acceptance (which cannot currently physically influence driving), the perception that in-vehicle monitors may increase crash risk as a barrier to adoption must still be noted.

Last, and related to the previous point, concerns have been expressed by young drivers, parents and researchers alike that there is risk of distraction with in-vehicle alerts, particularly given young drivers’ inexperience and limited attentional capacity (e.g. see J. D. Lee, 2007). Amongst the studies reviewed, these alerts were considered a potential “huge distraction with the beeping” (K. L. Young et al., 2003b, p.62) as if “you are a learner driver and it beeps, it might scare you and make you have a crash” (p. 60). Although drivers can technically control the presence of alerts in their vehicle (by driving safely), the perceived surprising or startling nature of these has been identified as a significant risk for young drivers in considering monitor adoption. “Annoyance”, stress and slight increases in mental workload (from $M = 27.87$, ‘some effort’ to $M = 34.90$, ‘a little effort’; Creaser et al., 2011, see also McCartt et al., 2010) have been self-reported while driving with a monitor. There is no young driver and monitoring specific empirical research on the topic of distraction and young driver monitoring published as of yet however.
B1.8 Discussion

The objective of this systematic review was to examine the young driver in-vehicle monitoring literature, and consider how this could inform understanding of the acceptability of SDSSs to potential young driver users. Specifically, the research question guiding the systematic review sought to identify the factors likely to impact on young driver acceptance and adoption of SDSSs. The review identified four primary factors (or analytical themes) linked to the willingness of young people to adopt driver monitoring technologies in their vehicles: perceived accuracy, perceived usability and the perceived gains and risks associated with use. These are now considered in light of SDSS features and functionality, and the potential for young driver acceptance and adoption of SDSSs.

Perceived accuracy and SDSS use

First, the perceived accuracy of in-vehicle devices emerged as an important determinant of young driver monitor acceptance in all of the six studies reviewed. This finding is broadly in line with the previously reviewed TA literature (e.g. the perceived accuracy factor can be seen to relate to others, such as the perceived usefulness of the technology, and effort and performance expectancy; Venkatesh et al., 2003) and factors from more context-specific TA models (e.g. trust in mobile technology; Kaasinen et al., 2011). Interestingly, although accuracy concerns were expressed throughout the literature reviewed, it is likely that with greater exposure to monitoring devices (and which become steadily more accurate as technology advances) users may grow to accept that the technology is accurate and reliable (e.g. see Creaser et al., 2011; Carney et al., 2010; Farmer et al., 2010). There is reason to anticipate a similar response to SDSSs, simply because many of the technological strengths of IVDRs are also provided through SDSSs. Smartphones have advanced accelerometers and GPS chipsets as standard for instance, two features frequently implemented in IVDR monitoring (Pitt et al., 2011). The majority of participants in Creaser et al.’s 2009 and 2011 TDSS studies, for example, reported beliefs that their SDSS was helpful and reliable.

On another level, however, certain unique threats to the accuracy of SDSSs must be acknowledged. For instance, GPS is not an infallible technology, as evident from empirical research (e.g. see McCartt et al., 2010; Bolderdijk et al., 2011). Even when working optimally, GPS produces estimate coordinates, which is, of course, problematic when a car is travelling on a road network where speed limits vary over a short distance (e.g. with posted speed limits moving from 100kmph, to 60kmph and 50kmph over 500 meters), or
when using forward collision warning systems that must continuously track the position of the user’s car and the leading vehicle. Atmospheric and terrestrial conditions can also impact on accuracy further, to the extent that there can be ‘outages’ of GPS coverage. These sources of error are not unique to SDSSs however. Rather they are a limitation of GPS chipsets in general. In fact, in certain situations SDSSs may be more accurate than IVDRs, as many typically feature Assisted GPS (A-GPS) as standard, which uses assistance servers such as cellular networks, and/or Wi-Fi, to compliment an inbuilt GPS chipset. This can often provide more accurate location estimates than GPS alone (Herrera et al., 2010), and offer a fail-safe alternative to calculating position in the event of poor-to-no satellite coverage.

Two further threats to the accuracy of SDSSs that are not shared with IVDRs however, are that they are more vulnerable to tampering by the driver, and to losing power due to battery depletion. SDSSs can be switched off, paused, or the app disabled and deleted with greater ease in comparison to permanently installed IVDRs, which activate automatically upon ignition. Regarding power depletion, the driver must ensure to charge their smartphone while driving with a SDSS, as apps requiring GPS drain battery power relatively quickly, potentially resulting in inaccurate records. However, provided that insurance companies, for example, require a specified amount of monitored miles to be driven before granting a discounted premium that would discourage switching off the app, and that young drivers ensure they charge their phone while driving, these should not prove significant issues.

*Perceived usability and SDSS use*

In addition to perceptions of accuracy, the extent to which young drivers find the technology easy to use is likely to be an important determinant of the willingness to uptake SDSSs. This was expected, as perceived usability-related factors, such as perceived behavioural control (TPB), perceived ease of use (TAM) or effort expectancy (UTAUT), have been identified as seminal factors and TA theory components underlying intention to adopt and novel technology adoption behaviours (e.g. Mathieson, 1991; Truong, 2009; Venkatesh et al., 2003). Specifically, cost, perceived technological complexity and the physical requirements of monitoring systems have all been identified as focal considerations to using IVDRs in the research reviewed here (e.g. McCartt et al., 2010; K. L. Young et al., 2003b). In applying this to the case of SDSSs, the following should be noted. First, SDSSs are available for download at relatively low costs. The iOnRoad app (pro version) for example, can be downloaded from the Google Play store for just €1.11.
Insurance companies also typically provide these to consumers for free (e.g. Axa, 2016). While the purchase of smartphones themselves may be considerable, this is not a cost of monitoring per se, as this cost remains to the user in the absence of monitoring. In addition, data suggest that 94% of those aged 19-24 in Ireland already possess smartphones capable of running a SDSS app (Thinkhouse.ie, 2014). Second, it is easier to install and maintain SDSSs than traditional IVDRs. The download and purchasing process for use can be completed in a user’s own time, requiring brief Wifi access and a low-cost docking mechanism or mount such that the smartphone alerts are visible and audible. Free software updates have become a routine aspect of phone app use, and would likely not present a challenge to users. Overall, SDSS perceived usability can be anticipated as high, as most users (even parents), are likely already familiar with app software and interfaces.

Perceived gains and SDSS use

The research reviewed would also suggest that young drivers engage in a rational choice process when deciding whether or not to accept and adopt in-vehicle monitors for use (e.g. Lerner et al., 2010; K. L. Young et al., 2003b). Simply put, novel monitoring technologies are most likely to be adopted when the perceived gains to employing such a system outweigh the potential risks. The importance of including factors related to the potential benefits of engaging with novel technology has been long recognised (e.g. the predictive value of the TAM perceived usefulness factor, and performance expectancy from the UTAUT; Suki & Suki, 2011; Tan, 2013; Venkatesh et al., 2003). Perhaps the most obvious benefit for young drivers is the potential to receive reduced insurance rates. On a more basic level, monitor use can improve costs by enhancing safe driving such that crashes (and subsequent claims and premium increases) occur less often. However ‘Pay-As-You-Drive’ or telematics based insurance has also become increasingly popular in recent years (e.g. Bolderdijk et al., 2011; Lahrmann et al., 2012). This involves the estimation of personalised accident risk and premiums, based on the data provided by monitors, such as SDSSs. It is anticipated that when considering SDSS adoption, young drivers will also value such factors. As stated, a number of Irish insurers, including Axa and No Nonsense Insurance, for example, are now providing discounted rates for young drivers, upon evidence of safe driving across a series of months. These typically offer an initial, guaranteed percentage discount (ranging from approximately 10-20% of an annual quote) for opting to drive with the SDSS alone, with the potential to earn an additional percentage reduction on receipt of
safe driving records over a specified period of documented driving within safety parameters.

A number of additional potential gains were identified throughout the review, and, as with the perceptions of accuracy, there was a sense that these could also be enhanced with increasing monitor experience. Approximately 80% of the participants in Farmer et al.’s 2010 study, for example, reported that IVDRs helped them to drive more safely and improve their skills after device usage. Young driver participants have also reported viewing IVDRs as a means to communicate more effectively about driving with their parents, as a valuable, objective learning tool, and a way in which to earn parental trust and rewards following extended periods of use (Guttman & Gesser-Edelsburg, 2011). Although SDSSs provided to young drivers by insurers do not typically involve a parental monitoring component, there is potential to incorporate this in SDSSs provided by road safety bodies, and it is likely that SDSS users will also experience positive developments regarding skills and overall road safety themselves.

Perceived risks and SDSS use

Perceived risks of driver monitoring did emerge from the research reviewed, broadly reflecting recent, emerging perceived risk TA model components (e.g. see Martins, Oliveira, & Popovič, 2014; Miltgen, Ale, Popovi, & Tiago, 2013). A potential loss of privacy (and subsequent strain in the parent/driver relationship) has been stressed by young drivers as a high cost to monitor use (Gesser-Edelsburg & Guttman, 2011; Guttman & Gesser-Edelsburg 2013). This perceived loss may be greater than that actually experienced however. Carney et al. (2010), for example, found that only 23% of their participants found monitoring to be an invasive experience, and over 90% reported they were glad they took part in the experiment and would recommend monitor use to their peers. In addition to this, with the increasing use of mobile location services (via apps such as Facebook etc. which monitor and update user locations) it is likely that such privacy issues may become less pronounced for this demographic, and particularly if such monitoring is performed by a personal phone. It is worth noting that approximately 40% of participants in the 2011 Creaser et al. study reported use of the TDSS as a privacy violation. This was based on a very brief exposure to the TDSS however, and overall evaluations were positive.

Last, risks associated with driving with a monitoring system that can actively intervene upon the driving task, or potentially distract drivers have also been voiced as influential factors for monitor acceptance (K. L. Young et al., 2003b). Evidence of
device tampering reported throughout a number of IVDR studies (e.g. McCartt et al. 2010) may be as a result of this dissatisfaction. At present, SDSSs cannot directly influence driving, as the smartphone is not connected to the vehicle’s hardware, and as such, RTC concerns due to automatic braking, or speed limiting etc. are not likely to influence acceptance or adoption decisions in this context. In line with this however, it is worth noting that as smartphone applications and indeed, smartphones themselves, can be easily switched off or disabled, this may actually render them more acceptable for young driver use. This potential to merely ‘switch off’ the app when risky driving is desired is of course, problematic, as it is unsafe, and could unfairly earn an insurance discount for a young person who is still driving dangerously at times. Ultimately however, should participants drive with a SDSS for even a portion of their total journeys, this could still have a greater protective effect on driving, than if a young driver disables their IVDR entirely by cutting wires etc. due to their dislike for an automatic device which they cannot personally control. With regards to the perceptions of distraction risk from in-vehicle monitoring, these are potentially warranted given the body of research regarding the negative impacts of phone use while driving (e.g. Haque & Washington, 2015), and concerns regarding the provision of real-time feedback voiced in the greater monitoring literature (e.g. Martens & Van Winsum, 2000). As SDSSs often function to block normal phone functionality however (e.g. by diverting incoming calls to voicemail, or muting notifications), SDSS usage may actually reduce the level of phone-related distraction experienced by a young driver overall, despite providing real-time feedback. This remains to be examined empirically however.

Limitations

The inconsistent quality of the six studies reviewed is an important limitation of the current analysis, that must be acknowledged and considered when interpreting and ascribing value to overall findings. Given the small number of research studies pertaining to young driver monitoring however, very few stringent quality inclusion criteria could be applied without excluding a significant proportion of the material available for review. In addition, other relevant samples and research may have been neglected as a result of the exclusion of studies not available in English, a common issue with systematic reviews (e.g. see Morrison et al., 2012). Narrative synthesis of qualitative and quantitative research in systematic reviews is also still in itself a somewhat contested practice (J. Thomas & Harden, 2008). Methods to guide the synthesis of qualitative research remain relatively undeveloped and the degree of subjectivity in coding and identifying themes (particularly when whole participant
transcripts are not available, as was the case in this review), has been criticised. Strong cases have been made for the inclusion of qualitative research syntheses in informing health-related policy and practice however, and its ability to provide valuable context to quantitative research despite methodological concerns has been acknowledged (Popay et al., 2006). In this case, given the largely qualitative methods employed by the studies reviewed, narrative synthesis of findings was necessary in order to successfully address the review question.

**B1.9 Contribution**

This study marks the first systematic review of the young driver monitoring acceptability literature conducted to date. It has highlighted key factors likely to influence young driver willingness to adopt and drive with SDSSs, and considered whether young drivers are likely to accept and adopt them, given the described, unique features of SDSSs. Although the low quality of the research studies reviewed must be acknowledged, these findings can still be used to inform the generation of a SDSS-specific, acceptance model to predict young driver usage of this novel technology, and have also highlighted means of potentially enhancing SDSS acceptance and usage to prospective users.

**B1.10 Conclusions**

The findings of this systematic review suggest that young driver acceptance of SDSSs is a complex topic. SDSS usage by young drivers will likely be largely influenced by their perceptions of accuracy, usability and the perceived risks and gains they associate with using such an app. The relatively high accuracy of modern smartphones, their low cost, the extent to which young people are familiar with and used to operating app technology (on smartphones they are likely to already possess), and the potential for SDSS insurance discounts all point to potentially promising levels of young driver acceptance of SDSSs in future.

As has been previously highlighted however, SDSSs are similar to IVDRs in many ways, but they do retain unique features and functionality that may influence acceptability for young drivers through as yet unanticipated means. In addition, the low quality of the existing in-vehicle monitoring acceptability studies reviewed here points to the need for a more objective, empirical assessment of this research topic in future. There is a clear need for empirical research on SDSS acceptability and acceptance, building on this systematic review and the broader TA literature.
Chapter 4 - Section B2: Building and Testing a Structural Model of SDSS Acceptance.

Note: An earlier version of this chapter was published in Accident Analysis and Prevention.


B2.1 Abstract

Background: SDSS-specific technology adoption research is necessary in order to successfully understand and predict young driver usage of this novel technology. The findings of Study 1 and review of the greater Technology Acceptance (TA) literature suggest that a model of SDSS adoption incorporate the perceived risks and gains associated with potential SDSS use, and additional social cognitive factors, such as perceived usability and social influence to predict acceptance and uptake. This has yet to be empirically tested however.

Aims: This study sought to build upon the foundation of evidence established in Study 1, and a review of the greater TA literature, to design and test a novel, structural model of young driver adoption of SDSSs using Structural Equation Modeling (SEM).

Methodology: A total of 333 smartphone users (18-24 years old) with full Irish driving licenses and current insurance completed a 20-minute, online questionnaire designed to measure the key factors in a novel model of SDSS adoption. Exploratory and Confirmatory Factor Analysis (CFA) procedures were conducted to establish the conceptual soundness of the model variables and structure. Structural equation modelling was then employed to identify the causal pathways predicting SDSS adoption, and to test for indirect effects and model fit. Multi-group invariance tests (across gender, risky driving propensity and adopter type) were completed at the CFA and SEM stages.

Findings: The adoption measure was found to be unsuitable for use, and acceptance (behavioural intention [BI] to use a SDSS) was taken as the primary outcome variable. The model reported 'excellent' fit, accounting for 72.5% of the BI outcome variance, and 58% of young drivers reported that they agreed, or strongly agreed that they ‘want to use this app’. Perceived gains and social influence reported significant direct effects on acceptance, with
perceived risks and social influence reporting significant indirect effects on BI, as mediated by perceived gains. Multi-group models demonstrated invariance of effects across gender, high and low risk drivers, and those likely or unlikely to adopt novel phone app technologies.

Conclusions: The model fit and invariance findings attest to the conceptual soundness of the model structure as a means of understanding young driver acceptance of SDSSs. High levels of young driver BI to use a SDSS were also reported throughout, and the key role of perceived gains and social influence in predicting SDSS acceptance was highlighted.

Implications: These findings suggest that SDSSs are acceptable for young driver use, and have identified potential means through which stakeholders may enhance future uptake. As such, further investigation of SDSS efficacy is now justified.

B2.2 Introduction and model overview

Building from the rationale and findings of Study 1 (Chapter 3), the central aim of this study, and chapter, was to test a novel model of young driver SDSS acceptance and adoption. This novel model was informed by existing theories and structures, such as the TAM (Davis, 1989) and the UTAUT (Venkatesh et al., 2003). It was also informed by the findings of the recent systematic review of the factors that are linked to the acceptance and adoption of IVDR monitoring by young drivers (Study 1, Chapter 3). This model focused on adoption (i.e. whether an individual acts to use the SDSS or not) and BI (i.e. the manifestation of acceptance) as core outcomes (see Figure 4 below). This is because the act of using a SDSS is likely to be a planned one, involving controlled cognitive processing of risk/gains as well as other factors (e.g. K. L. Young et al., 2003b). In summary, this model proposed that SDSS adoption could be directly predicted by BI, perceived gains, perceived risks and the construct of perceived usability (i.e. how easy the app is to use). The BI variable was then anticipated to be directly influenced by perceptions of SDSS gains and risks, and both directly and indirectly influenced by four exogenous variables - social influence, perceived usability, attitudes and perceived accuracy. Last, a key individual difference variable, delay discounting, was predicted to influence perceptions of gains relating to SDSS usage, and as such, also indirectly influence acceptance (BI).
Perceived gains and risks

It was anticipated that the perceived gains (e.g. opportunity to earn insurance discounts) and risks (e.g. threats to privacy/security of recorded data) associated with a SDSS would have positive and negative effects, respectively, on intentions to uptake and adoption of a SDSS. ‘Perceived gains’, as measured in the current study, relates to seminal TA factors such as perceived usefulness and performance expectancy which have emerged as instrumental in past research on driver monitoring and TA and adoption (e.g. Creaser et al., 2009; 2011; Davis, 1989; Venkatesh et al., 2003). In a SDSS use context, perceived gains primarily refer to the potential to improve driver skills and safety, and obtain discounted insurance rates.

Perceived risks then, relate to the potential risks associated with SDSS use, such as whether or not engaging with the app could cause distraction while driving (e.g. K. L. Young et al., 2003b), the risks of private driving data being abused by monitoring parties, or the perceived potential for increases in insurance premiums (e.g. Lerner et al., 2010). Technology acceptance studies are increasingly incorporating perceived risk variables into proposed theories and models of acceptance (e.g. Martins et al., 2014; Miltgen et al., 2013).
addition, as with perceived gains, concerns over the risks associated with SDSS use emerged strongly from the young driver IVDR acceptability systematic review. In line with TA literature, the current study hypothesised that the perceived gains associated with SDSS use would have a positive effect on intention to adopt and adoption of a SDSS, and perceived risks, significant negative effects on these variables.

*Delay discounting*

The perceived risks and gains concepts implicitly assume that individuals rationally assess costs and benefits to decide upon an action that maximises personal advantage. Such an assumption, however, does not account for individual differences in the way perceived risks and gains are compared and evaluated during the decision-making process. When making a decision, costs and benefits in the immediate future may strongly outweigh longer-term gains, an effect known as delay discounting (Kirby & Marakovic, 1996; Kirby, Petry, & Bickel, 1999). That is, the value of future gains can be discounted based on the delay prior to receiving them. Notably, the majority of gains associated with SDSS use are delayed. Insurance discounts, for example, are typically provided only following a monitored period of safe driving; improvements in driver skill will only occur over time. Within the current model, perceived gains of SDSS use were understood to motivate intention and adoption behaviour. Thus, it was anticipated that young drivers who discount delayed rewards more strongly would record lower perceptions of SDSS gains and, consequently, reduced BI and adoption rates.

*Social influence*

This model proposed that a young driver’s perceptions of risks and gains associated with SDSS use could also be influenced by the beliefs and values upheld by important others. Although this did not emerge from the systematic review of the young driver monitoring acceptability literature, the salience of the peer group in influencing norms, decision-making and behaviours for this particular age group (18-24) has been widely documented (e.g. Butler-Barnes, Estrada-Martinez, Colin, & Jones, 2015; Echeverría, Gundersen, Manderski, & Delnevo, 2015; Widman, Choukas-Bradley, Helms, & Prinstein, 2016), even within the driving literature (e.g. see Pradhan et al., 2014). Defined here as the degree to which a young driver perceives that peers, family members or co-workers believes he or she should use the technology in question, social influence has been included as a core construct. Positive, significant effects of this variable on willingness to use new technology have been reported within models such as the UTAUT, and as ‘subjective norm’ within the TPB and TRA (Azjen, 1991; Sheppard, Hartwick, & Warshaw, 1988; S. Taylor & Todd, 1995a; Venkatesh
et al., 2003; Venkatesh et al., 2012). As such, it was expected that higher positive social influence scores (i.e. the young driver perceives that friends, peers, co-workers etc. want them to use SDSS technology) would directly predict higher perceived gains and lower perceived risks associated with SDSS usage, in addition to higher acceptance and adoption rates.

**Perceived usability**

Perceived usability can refer to perceived ease of use (Davis, 1989), perceived behavioural control (S. Taylor & Todd, 1995a), complexity (R. L. Thompson, Higgins, & Howell, 1991), or effort expectancy (Venkatesh et al., 2012). In the current study, perceived usability is defined as the ease with which the young driver believes they can access, download and incorporate the use of a SDSS while driving. As such, it assesses how easy it is for young drivers to, for example, obtain a dashboard mount for their smartphone, or whether they currently have the storage capacity to run it on their smartphone. Given the predictive relationship between the conceptually similar perceived behavioural control construct and BI in the established TPB, and the findings of the acceptability systematic review (Study 1, Chapter 3) it was anticipated that perceived usability would have a positive, direct effect on SDSS acceptance and adoption. It was also contended that higher levels of perceived usability would result in higher perceptions of gains, and lower perceptions of risks, and thus indirectly influence BI and adoption rates.

**Attitudes**

Attitudes towards acceptance and adoption of technology have long been incorporated into TA theories (Compeau & Higgins, 1995; Vallerand, 1997, see also Venkatesh et al., 2003 for review). Here, young driver SDSS attitudes were defined and measured as the positive or negative feelings they have in relation to using this technology. In keeping with empirical findings in relation to models such as the TPB, it was proposed that higher positive attitude scores would have positive effects on intention to use (i.e. acceptance), and adoption. It was also proposed that an individual’s attitude towards driving with a SDSS would influence their perceptions of the risks and gains associated with SDSS usage. ‘Liking’ the idea of using a monitoring device is a basic emotional response, which is then proposed to be rationalised by reference to perceived risks and gains. An individual who dislikes using a SDSS, for example, may report greater perceived risks of usage, and also be less likely to accept and use a SDSS. Accordingly, it was anticipated that more negative attitudes towards SDSS use would result in lower BI and adoption scores, also as mediated by perceived risks. Young drivers with more favourable attitudes towards SDSSs however, may be more inclined
to identify the potential gains associated with usage, and thus report higher BI and adoption rates.

*Perceived accuracy*

Perceived accuracy is a relatively novel inclusion in a TA model, although it broadly relates to previous TA constructs, such as trust in technology, which have been found to have positive effects on willingness to use new technological devices and programs (e.g. Kaasinen et al., 2011; Muir & Moray, 1996). Young drivers have consistently expressed a preference (or indeed, requirement) for accurate, reliable monitoring devices across a number of qualitative studies, some to the extent that they would be unwilling to use them if they weren’t “100% accurate” (K. L. Young et al., 2003b, p. 68). As such, it was expected that perceptions of accuracy would directly, positively influence intention to use a SDSS, and, as such, also influence adoption behaviour. In addition, it was posited that perceptions of accuracy would influence young driver perceptions of gains (positively) and risks (negatively), and thus, also indirectly influence BI and adoption.

### B2.3 Rationale for the current study

Given the novelty and unique features of SDSS technology, it is not yet clear whether young drivers consider them acceptable for use, and what influences an adoption decision in this context. This is of key importance, as the IVDR literature attests to the aversion that some young drivers have to monitoring (e.g. McCartt et al., 2010). If found to be effective in reducing young driver RTC risk, SDSSs will need to be marketed to young people in order for their protective effects to be experienced. Evidence-based knowledge as to what factors influence an adoption decision will be crucial in this context, to aid in the design of persuasive communication strategies promoting uptake. As yet, and as described throughout the acceptability systematic review (Study 1, Chapter 3) however, research examining young driver acceptance of conceptually similar IVDR technology has been of low quality, primarily qualitative in nature, and lacked behavioural adoption or even intention-to-use measures. As such, this study seeks to build from Study 1 findings, and empirically identify the core factors influencing young driver acceptance and adoption of SDSSs, which can inform the greater TA, and driving research literatures, and the work of SDSS manufacturers, marketing teams and road safety bodies.

Thus, the current study employed a survey-based design that aimed to test the proposed, context-specific, SDSS acceptance and adoption model (see Figure 4 above),
through measuring young driver responses to a series of items designed to measure factors associated with SDSS acceptance, and the act of adoption itself. Specifically, with the aim of conceptually and methodologically advancing the existing literature, the following hypotheses were explored in the current study:

1. This model hypothesises that acceptance (BI), perceived gains and risks, and perceived usability are direct predictors of SDSS adoption.
2. Acceptance (BI) is hypothesised to be directly and indirectly predicted by four exogenous variables - social influence, perceived usability, attitudes and perceived accuracy, and directly predicted by perceived risks and gains.
3. These four exogenous variables are also anticipated to significantly influence perceptions of SDSS gains and risks.
4. A key individual difference variable, delay discounting, is anticipated to predict perceptions of gains relating to SDSS usage, and as such, indirectly influence acceptance (BI).

As stated, the central aim of this study was to test a novel model of young driver SDSS acceptance and adoption. Of note however, during the initial screening of the data collected to test this model, it became apparent that the adoption measure would not be suitable for use (outlined in Section B2.4). As such, the model became one of SDSS acceptance, with all pathways/hypotheses relating to adoption being removed. The model modifications are outlined in detail in the results section (Section B2.4, see Figure 5).

B2.4 Method

Participants

The sample was recruited predominantly via a national social media campaign, utilising networks such as Facebook and Twitter to advertise links to the online study (e.g. the Road Safety Authority of Ireland Facebook page promoted the study). Given the age profile of the target sample, a series of recruitment emails were also sent to universities throughout Ireland to advertise the research. Participation was incentivised by informing prospective participants that by completing the survey they would be entered into a draw for an electronic tablet. All advertising materials informed the reader that only individuals with a
full Irish driving licence, current insurance and smartphone, aged between 18-24 years (inclusive) would be eligible to take part.

A total of 333 participants (34% male, $n = 113$, 66% female, $n = 220$) took the survey to completion and were included in the final CFA and SEM analyses. Such a sample size (i.e. > 300 participants) is considered appropriately large for the present EFA, CFA and SEM analyses (Field, 2009; Byrne, 2010; Kline, 2011). Participant age ranged from 18-24 years, with a mean age of 21.38 ($SD = 1.77$). The majority were students (68% undergraduate, $n = 225$, 18% postgraduate, $n = 61$, 1% 2nd level, $n = 5$). Eleven per cent ($n = 36$) were employed and 2% ($n = 6$) unemployed. Participant driving experience ranged from less than 1 to 7 years ($M = 2.5$ years; $SD = 1.80$).

**Measures**

Given the relative novelty of the perceived accuracy and perceived risks constructs, the majority of the items used to assess these were developed for the purposes of this study, in accordance with guidelines from DeVellis (2012). All other items were adapted from existing, psychometrically sound, scales from the TA and TPB literature (e.g. see Francis et al., 2004; Venkatesh et al., 2003), with a total of 34 items employed. These were reviewed by two young driver focus groups (Group 1, $n = 4$; and Group 2, $n = 4$). Participants examined the measures in accordance with two criteria: 1) comprehensiveness (i.e. the degree to which the items sufficiently sampled the content domain); and 2) clarity (i.e. how clearly each item was worded). They were also asked to identify any items they perceived to be overly similar (i.e. redundant). These responses were examined, and the measures revised and edited to accommodate their feedback.

**Factor scales.** A total of four items were generated and selected to assess perceived accuracy (e.g. ‘this app would monitor my driving accurately’). Perceived risks were measured by five items (e.g. ‘this app would distract me while driving’). Eight items were included to assess perceived gains (e.g. ‘using this app would help me to drive better’). Perceived usability was measured by eight items (e.g. ‘I have the skills and abilities to use this app while driving’). Social influence was assessed by four items (e.g. ‘my friends would want to use this app’). A total of three items were included to assess attitudes (e.g. ‘using this phone app is a good idea’). Behavioural intention (acceptance) was measured by two items (‘I want to use this app’, and ‘I intend to use this app’). Responses to these variables were recorded along a five-point Likert scale, where 1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree and 5 = strongly agree. Cronbach’s alpha (i.e. reliability) scores for the final versions of these variables are presented in Section B2.4.
Delay discounting. The delay discounting variable was measured through the use of the 27-item Monetary Choice Questionnaire (MCQ; Kirby et al., 1999). For each item on this questionnaire, participants choose between a smaller, immediate amount of money, and a larger delayed amount (e.g. ‘Would you prefer €34 today, or €35 in 186 days?’). Responses on the 27 items were grouped into three categories according to the magnitude of the delayed rewards (i.e. small, medium and large), and $k$-values, indexing the extent to which respondents chose smaller immediate amounts over larger delayed ones, were then determined for each monetary value and a geo-mean score obtained for the total delay discounting score.

Adoption. The behavioural adoption measure was administered via email one week after participants completed the online survey. The young drivers were first thanked for their participation, and then asked if they would like to download a linked SDSS (similar to the one described in their study) for use. They were informed that in order to do this, they would be asked to provide their unique identifier number (as entered by them in the original survey, and consisting of the last three digits of their phone number and numeric month and year of birth) and would then be brought to the SDSS download page (they were brought to the iOnRoad homepage). Those that clicked the link and entered their unique ID were marked as ‘yes adopt’, and their adoption response linked to the original questionnaire responses via the unique identifier code. Those who did not respond to the email were marked as ‘no adopt’.

Invariance test variables

Invariance tests were also conducted during the CFA and SEM analyses to assess the factor structure and fit of the SDSS acceptance model across gender, risky driving propensity and general app adoption likelihood. These groupings were selected as research has documented differences in the driving, and app use, related perceptions, intentions and behaviours of members of these groups (e.g. Habtemichael & de Picado-Santos, 2013; Holland, Geraghty, & Shah, 2010; Moore, 2014).

Risky driving propensity. The Driver Behaviour Questionnaire (DBQ; Iversen, 2004), was included in the survey. The DBQ is a 24-item, self-report measure of driver behaviour, including subscales, such as ‘Cautious and Watchful Driving’, or ‘Violations of Traffic Rules/Speeding’. Of main interest to the current study was the latter, consisting of six items, including items such as how often do you ‘Break 80km/h speed limits by more than 10km/h’. Responses were recorded on a five-point Likert scale (ranging from 1 ‘never’, to 5 ‘very often’), and reported good internal consistency, $a = .86$. Higher DBQ subscale scores indicated higher levels of reported violations and speeding (i.e. greater risk-taking). Drivers
were later split into high or low-risk drivers based on their scores along this subscale, to see if the factor structures and overall model functioned similarly across both groups.

**Adopter type.** An individual’s tendency to generally adopt novel phone app technology (a single item measure based on the ‘Technology Adoption Lifecycle’; TAL theory; Moore, 2014) was also assessed. This theory purports that people can be categorised by their general tendencies to adopt novel technology. ‘Innovators’, for example, are technology enthusiasts, the ‘first responders’ to uptake newly released devices, who enjoy and adopt technology for its novelty. Conversely, ‘laggards’ are resistant, and have aversions to, new technology, and are typically the last group of people to adopt an innovation. Five such categorisations along a continuum exist (comprising of innovators, early adopters, early majority, late majority and laggards), and participants were asked to select from a list of five items, which best described their typical approach to using phone apps (e.g. ‘I usually download and use the latest phone apps’, which was the innovator description, followed by the early adopter description, consisting of ‘I usually download and use new phone apps, provided they are useful’). Those who identified as ‘innovators’ or ‘early adopters’ were classified as likely SDSS adopters, and those who identified as ‘early majority’, ‘late majority’ or ‘laggards’ were deemed unlikely to adopt new phone app technology, and invariance across the two groups examined.

**Demographic variables - gender.** Standard demographic information was also gathered during the survey, including participant gender, age, and occupation, number of months of licensure, and a brief series of other driving-related measures (e.g. the number of penalty points accrued by the young driver in the past three years, and whether they had been involved in a RTC). Invariance was later tested across male and female participants.

**Procedure**

Participants were recruited through a nationwide social media campaign, which shared the link to the online survey. The survey took approximately 20 minutes to complete, during which young drivers first entered an anonymous identifier code (consisting of the last three digits of their phone number, and their numeric month and year of birth), answered a brief series of demographic questions, and then responded to the DBQ subscale. Following this, they read two passages describing a typical SDSS, and were presented with a selection of images of the app ‘in action’ to introduce them to the concept of smartphone monitoring. Last, they were asked to imagine they were being offered such an app, and then respond to the 34 items of the SDSS acceptance scale. When they had finished this, participants were thanked for taking part, and then informed that they would receive a brief follow-up email.
one week after survey completion. They were then automatically navigated to a new, separate survey, where they solely provided an e-mail address to enter in the draw for the tablet. This ensured that the participant could be contacted to receive the SDSS adoption measure email, while ensuring the anonymity of their initial responses. When later sent the adoption email, they were provided with an invitation to access a free SDSS (the iOnRoad app) via an attached link. In order to access this, and upon clicking on the link, they were first prompted to enter their unique identifier code. This enabled their initial questionnaire responses to be linked to their adoption decision.

**B2.5 Results**

*Data analytic strategy*

Prior to commencing statistical analyses, participant data were assessed for any missing values. As these data were gathered via an online survey using SurveyMonkey™, it was possible to require responses for each questionnaire item prior to granting access to the next question. Thus, any participants who completed the survey in full had responded to every item, and no data were missing. Any data from participants who did not complete the survey in full was not included in analyses.

Following this, and assessments of the distributions of the measured variables, it became apparent that the adoption measure was unsuitable for use as an outcome measure in the current study. A number of participants did not provide email addresses during the survey, or provided incorrect ones such that they did not receive the link to the adoption measure \((n = 32)\). A small number of others entered their unique identifier code incorrectly, such that their adoption response could not be linked and used \((n = 6)\). In all, a heavily skewed \((90\% \text{ ‘no adopt’ and } 10\% \text{ ‘yes adopt’})\), and likely inaccurate distribution \((\text{as any participant who did not respond to the adoption email was marked as a ‘no adopt’ response, when they simply may have not received the email})\) was recorded, which was incompatible for SEM or logistic regression. Consequently all hypothetical pathways pertaining to the adoption measure were removed from the model, and acceptance (BI) was taken as the core outcome variable (see Figure 5 below) for this study. Each pathway represents a hypothesis for testing.
Factor analysis was first conducted on the questionnaire/scale items in order to examine the underlying latent factors of SDSS acceptance, and the relationships of the adapted items to these. Two types of factor analysis are typically employed in scale development/assessment: exploratory factor analysis (EFA) and confirmatory factor analysis (CFA). Exploratory factor analysis enables items to relate to any of the underlying factors, and thus it is optimal for use when the underlying relationships between items and factors are unknown (i.e. not formally established; e.g. Field, 2009). Accordingly, the item pool was first subjected to an EFA.

Following this, a measurement model was built, and a CFA was conducted. This is a powerful, multivariate analytic tool belonging to the family of structural equation modeling (SEM) that assesses associations between specified latent constructs, requiring an empirical or theoretical basis for an assumed factor structure (as is provided during an EFA; Fabrigar, Wegener, MacCallum, & Strahan, 1999). Drawing from the findings of the CFA, a structural model was then built and tested using SEM. Both CFA and SEM analyses allow researchers to specify relatively ‘error free’ latent variables while correcting for any potential biases resulting from random or external variances (Langdridge, Sheeran, & Connolly, 2007; MacCallum & Austin, 2000). Achieving model fit criteria in CFA and SEM confirms the “conceptual soundness of the latent variables used in the final model”, ensuring that any
conclusions drawn regarding relationships between variables are not “misleading” (Schreiber, Nora, Stage, Barlow, & King, 2006, p. 335).

Invariance tests were also conducted during the CFA and SEM analyses to assess the factor structure of the SDSS acceptance model across gender, risky driving propensity and adopter type. By assessing invariance, it is possible to determine if individual factor subscales/items function similarly across different groups, attesting to how robust the model is (Byrne, 2010).

**Normality**

The distribution of scores on each scale measure (i.e. perceived accuracy, risks, gains and usability, social influence, attitudes and delay discounting) was inspected for normality prior to commencing statistical analyses. Graphical representations of the data were examined visually, in conjunction with examinations of skew and kurtosis values for each scale. Variables with skew values >.8, and kurtosis values >3, in addition to significant Kolmogorov-Smirnov values (i.e. \( p < .05 \)) were taken to require appropriate transformations due to non-normality (Tabachnick & Fidell, 2007).

Following assessment of the seven factors, the acceptance measure and related measured variables (e.g. the DBQ subscale scores), the delay discounting measure was the sole variable found to be non-normally distributed (skew = 3.97, kurtosis = 19.04, \( p < .001 \)). This was subject to a logarithmic transformation, whereupon scores were found to lie within the normal distribution range. Normality assessments of all the scale and related variables (e.g. scores on the DBQ subscale) were repeated throughout the different steps of the statistical analyses following, for example, the removal of participants, or the removal of items from a scale. Data distributions were found to remain within normal ranges following all of these.

**Exploratory Factor Analysis**

A principal axis factoring (PAF) analysis was conducted on the initial 32 items \( (n = 358) \) with oblique rotation (direct oblimin, delta set at zero). An oblique rotation was employed, as a degree of inter-relatedness amongst the factors was expected. The BI and delay discounting items were not included at this stage. The BI measure was not included as it was an established outcome measure, and the delay discounting items (providing binary choice ‘yes’, ‘no’ response type data) and means of calculating the overall score for this measure rendered it unsuitable for factor analysis (Kirby et al., 1999).

Items without any inter-item correlations < .3, or with correlations > .9 were deleted \( (n = 3) \). A parallel analysis (O' Connor, 2000) and examination of the scree plot indicated that
four factors should be retained (Costello & Osborne, 2005). The analysis was repeated forcing a four-factor solution. The Kaiser-Meyer-Olkin (KMO) measure verified the sampling adequacy for this analysis ($KMO = .90$, scores must be $>.60$ to indicate this), and Bartlett’s test of sphericity was significant ($p < .001$), indicating that correlations between items were sufficiently large for PAF (Tabachnick & Fidell, 2007). Items were retained with loadings higher than or equal to .30 (Field, 2009), with the removal of any that cross-loaded at a greater value than .32 ($n = 25$ items retained, see Table 3 below) (Costello & Osborne, 2005; Worthington & Whittaker, 2006). The four-factor solution was found to account for $55.32\%$ of the total variance. Following reliability assessments of the factors, the remaining clustered items ($n = 23$) suggested these were ‘perceived gains’ ($n = 10$, $\alpha = .90$, $M = 24.81$, $SD = 7.16$) ‘perceived risks’ ($n = 4$, $\alpha = .72$, $M = 19.17$, $SD = 3.94$), ‘social influence’ ($n = 4$, $\alpha = .85$, $M = 11.33$, $SD = 3.20$) and ‘perceived usability’ ($n = 5$, $\alpha = .71$, $M = 10.20$, $SD = 3.13$). The seven-factor model was then revised (see Figure 6 below), with all original hypotheses retained for testing, except for those in relation to perceived accuracy and attitudes.

![Image of revised five-factor SDSS acceptance model](image-url)

*Figure 6. Revised five-factor SDSS acceptance model.*
Table 4
Factor loadings for exploratory factor analysis items.

<table>
<thead>
<tr>
<th>Original Item</th>
<th>Item Description</th>
<th>PG</th>
<th>PR</th>
<th>SI</th>
<th>Us</th>
</tr>
</thead>
<tbody>
<tr>
<td>PA2</td>
<td>I could depend on this app to work reliably</td>
<td>.47</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG1</td>
<td>This app would be useful when driving</td>
<td>.66</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG2</td>
<td>Using this app would help me to drive better</td>
<td>.78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG3</td>
<td>Using this app would help me to drive more safely</td>
<td>.81</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG4</td>
<td>Using this app would enable me to obtain cheaper insurance</td>
<td>.54</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG5</td>
<td>Using this app would help me avoid penalty points</td>
<td>.66</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AT1</td>
<td>Using this phone app is a good idea</td>
<td>.60</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AT2</td>
<td>I like the thought of driving with this phone app</td>
<td>.57</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AT3</td>
<td>Using this phone app would be a positive experience for me</td>
<td>.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG6</td>
<td>Driving with this app would reduce my fuel consumption and emissions</td>
<td>.40</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PA3</td>
<td>This app would set off false alerts in my car</td>
<td></td>
<td>.44</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PA4</td>
<td>It would be possible to ‘trick’ this phone app to obtain insurance benefits</td>
<td></td>
<td>.50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR1</td>
<td>This app would distract me while driving</td>
<td></td>
<td>.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR2</td>
<td>This app would release my private data without my knowledge/permission</td>
<td></td>
<td>.59</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR4</td>
<td>Using this app would increase my insurance premium</td>
<td></td>
<td>.57</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR5</td>
<td>This app would record errors and unfairly increase my insurance premium</td>
<td></td>
<td>.71</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SI1</td>
<td>My friends would think highly of me for using this app</td>
<td></td>
<td></td>
<td>-.50</td>
<td></td>
</tr>
<tr>
<td>SI2</td>
<td>My friends would want to use this app</td>
<td></td>
<td></td>
<td>-.51</td>
<td></td>
</tr>
<tr>
<td>SI3</td>
<td>Other than friends, people who are important to me (e.g. family, co-workers) would think I should use this app</td>
<td></td>
<td></td>
<td>-.81</td>
<td></td>
</tr>
<tr>
<td>SI4</td>
<td>Other than friends (e.g. family, co-workers), people who influence my behaviour would think I should use this app</td>
<td></td>
<td></td>
<td>-.93</td>
<td></td>
</tr>
<tr>
<td>PU1</td>
<td>I am confident I could install and update this app on my smartphone</td>
<td></td>
<td></td>
<td></td>
<td>.65</td>
</tr>
<tr>
<td>PU2</td>
<td>It would be easy for me to obtain a mount for my smartphone</td>
<td></td>
<td></td>
<td></td>
<td>.65</td>
</tr>
<tr>
<td>PU3</td>
<td>I have the storage space on my smartphone to install and run this app</td>
<td></td>
<td></td>
<td></td>
<td>.47</td>
</tr>
<tr>
<td>PU6</td>
<td>I have the skills and abilities to use this app while driving</td>
<td></td>
<td></td>
<td></td>
<td>.61</td>
</tr>
<tr>
<td>PU7</td>
<td>I would have to rely on others to help me use this app</td>
<td></td>
<td></td>
<td></td>
<td>.50</td>
</tr>
</tbody>
</table>

*Note. PA = Perceived accuracy; PG = Perceived gains; AT = Attitudes; PR = Perceived risks; SI = Social influence; PU = Perceived usability.*
Confirmatory Factor Analysis

In constructing and testing a measurement model as per a CFA, first, univariate and multivariate normality of the variables were assessed. Scores for each factor were normally distributed, as evidenced by skewness scores < .8 and kurtosis scores < 3 (Tabachnick & Fidell, 2007). Multivariate normality was also assessed by performing a Mahalanobis distance analysis (Byrne, 2010), leading to the exclusion of data for 25 participants (remaining n = 333).

A measurement model was then constructed (see Figure 7 below) and tested using Analysis of Moment Structures (AMOS) software version 20. The delay discounting measure was not included in the CFA given, as previously stated, these scores were unsuitable for factor analysis. The BI (acceptance) measure was included at this point, to ensure it was distinct from the other variables measured.

Kline’s (2011) recommendations for model fit evaluation were followed. For the current study, absolute fit was determined using the chi-square/df ratio (Q) and the Root Mean Square Error of Approximation (RMSEA). In addition, Bentler’s comparative fit index (CFI) was used to assess comparative fit. Stringent fit criteria and thresholds were applied. Q < 5, RMSEA ≤ .08 and CFI ≥ .90 were taken to signify adequate or good fit, whereas Q < 2, RMSEA ≤ .06 and CFI ≥ .95 denoted excellent fit (Byrne, 2010; Kline 2011; Tabachnick & Fidell, 2007). The chi-square statistical difference test was reported as per current guidelines (Kline, 2011; B. Thompson, 2004) and the Akaike Information Criterion (AIC) and delta AIC scores (Δ AIC, where values > 10 suggest maximum support for the adjusted model) were also employed to compare the relative fit of competing models (Burnham & Anderson, 2002). Competing models refer to instances here where, for example, statistical output suggested the addition of new structural pathways, or that certain items should be excluded from the model to improve fit. The adjusted model could then be compared to the original model to evaluate the statistical impact of these changes, in addition to considering the theoretical implications of any such modifications.

Initial fit for the measurement model was poor, Q = 3.56, RMSEA = .09 (90% CI = .08 - .09), CFI = 0.87 (see Table 4 below). Based on examinations of factor item content and factor loadings, seven items deemed to have less conceptual relevance to their factor, and lower loadings, were deleted (see Appendix E for the final items included in the acceptance measure). The five factors were then composed as follows: perceived gains (n = 5, α = .89, M = 18.47, SD = 3.82); perceived risks (n = 4, α = .74, M = 11.04, SD = 2.90); social
Figure 7. Path diagram of the SDSS acceptance measurement model.

Table 5
Fit statistics of original and revised versions of the SDSS acceptance measurement model.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$(df)</th>
<th>Q</th>
<th>RMSEA (90% CI)</th>
<th>CFI</th>
<th>AIC</th>
<th>$\Delta$ AIC</th>
<th>$\Delta\chi^2$</th>
<th>$\Delta$ df</th>
</tr>
</thead>
<tbody>
<tr>
<td>25 Items</td>
<td>944.63(265)</td>
<td>3.57</td>
<td>.09 (.08 - .09)</td>
<td>.87</td>
<td>1064.63</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>18 Items</td>
<td>295.06(125)</td>
<td>2.36</td>
<td>.06 (.06 - .07)</td>
<td>.95</td>
<td>387.06</td>
<td>677.57</td>
<td>649.87***</td>
<td>140</td>
</tr>
<tr>
<td>Error co-</td>
<td>256.47(124)</td>
<td>2.07</td>
<td>.06 (.05 - .07)</td>
<td>.96</td>
<td>350.47</td>
<td>36.59</td>
<td>38.59***</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. $X^2 =$ Chi-Square; df = Degrees of Freedom; Q = Chi-Square/df Ratio; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; AIC = Akaike’s Information Criteria; $\Delta$ AIC = Delta Akaike’s Information Criteria; $\chi^2$ diff = Chi-Square Difference Test.
influence ($n = 3, \alpha = .80, M = 9.56, SD = 2.32$); perceived usability ($n = 4, \alpha = .72, M = 15.95, SD = 2.51$), and; BI ($n = 2, \alpha = .90, M = 6.75, SD = 2.04$). These changes improved the measurement further residual error covariance to the measurement model (between two items on the perceived gains variable), following which excellent model fit was achieved, $Q = 2.07$, RMSEA = .06 (90% CI = .05 - .07), CFI = .96, $\Delta$ AIC = 36.59, $p < .001$.

**Measurement model invariance**

Invariance tests were then conducted to assess the factor structures within the SDSS measurement model using CFAs. This involved fitting the model across gender (male versus female), risky driving propensity (high versus low-risk drivers), and adopter type (likely versus unlikely adopters). Participants were distinguished as high or low-risk drivers based on their DBQ scores using a median split. A chi-square analysis confirmed that those in the high-risk group reported higher levels on a separate, composite risky driving behaviour score. This consisted of their reported number of penalty points and incidence of RTCs in the past three years, and incidences of drink driving and on-road racing in the past six months, $\chi^2 (1) = 38.30, p < .001, V = -.34$.

Regarding adopter type, participants were split into either likely or unlikely adopters based on their TAL score (Moore, 2014). Those who identified as ‘innovators’ or ‘early adopters’ were classified as likely SDSS adopters, and those who identified as ‘early majority’, ‘late majority’ or ‘laggards’ were deemed unlikely to adopt new phone app technology. A chi-square analysis indicated that likely adopters were associated with responding to adopt the emailed SDSS (i.e. the adoption measure), rather than those in the unlikely group, $\chi^2 (1) = 4.18, p = .04, V = .11$. The limitations associated with the adoption measure have been noted however.

Chi-square difference tests were the primary means to determine whether the unconstrained model and the model with constrained pathways were significantly different, although these were examined in conjunction with changes in CFI fit indices. A significant change in chi-square model fit between the models, or increase in CFI value >.01 was taken as evidence that there were path differences between the two, i.e. non-invariance (Byrne, 2010; MacCallum, Widaman, Zhang, & Hong, 1999). Identical, rigorous fit criteria were applied as per the initial CFA.

**Gender invariance**

The measurement model was first tested across gender using multiple group CFAs. First, a baseline model was established to examine model fit of the hypothesised model for both gender groups separately. Model fit was excellent for males, $\chi^2 (124, n = 113) = 164.82; p$
Next, configural invariance was examined in order to establish model fit across gender. Configural invariance (i.e. all parameters to be freely estimated) was confirmed; $\chi^2_{(248)} = 419.65; p < .001; Q = 1.69; \text{RMSEA} = .05 (90\% \text{ CI} = .04 - .05); \text{CFI} = .95; \text{AIC} = 607.65$. Metric invariance was also tested by constraining the factor loadings across gender groups to assess if the factor loadings (i.e. the relationship between the latent factors and their indicators), functioned similarly across groups. The results reported no significant differences between the constrained and unconstrained configural model (see Table 5). Thus, the factors were taken to function similarly for both male and female young drivers.

Table 6
Configural and metric invariance across gender.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$(df)</th>
<th>RMSEA (90% CI)</th>
<th>CFI</th>
<th>$\chi^2_{\text{diff}}$</th>
<th>$\Delta \text{ df}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>419.65(248)</td>
<td>.05 (.04-.05)</td>
<td>.95</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Model B</td>
<td>438.27(261)</td>
<td>.05 (.04-.05)</td>
<td>.95</td>
<td>18.62</td>
<td>13</td>
</tr>
</tbody>
</table>

Note. Model A = Configural, unconstrained model, Model B = Factor loadings invariant; $\chi^2 = \text{Chi-Square}; \text{df} = \text{Degrees of Freedom}; \text{RMSEA} = \text{Root Mean Square Error of Approximation}; \text{CFI} = \text{Comparative Fit Index}; \chi^2_{\text{diff}} = \text{Chi-Square Difference Test}.$

Risk driving propensity invariance

As with gender, invariance tests were conducted across high and low-risk drivers using multiple group CFAs. A baseline model was established to examine model fit of the hypothesised model for both risk groups separately. Model fit was excellent for both high-risk, $\chi^2_{(124, n = 175)} = 196.64; p < .001; Q = 1.586; \text{RMSEA} = .06 (90\% \text{ CI} = .04 - .07); \text{CFI} = .96; \text{AIC} = 290.64$, and low-risk drivers, $\chi^2_{(124, n = 158)} = 193.54; p < .001; Q = 1.56; \text{RMSEA} = .06 (90\% \text{ CI} = .04 - .08); \text{CFI} = .96; \text{AIC} = 287.54$.

Configural invariance was then examined in order to establish model fit across risky driving propensities. This was confirmed; $\chi^2_{(248)} = 390.18; p < .001; Q = 1.50; \text{RMSEA} = .04 (90\% \text{ CI} = .03 - .05); \text{CFI} = .96; \text{AIC} = 549.14$. Metric invariance was also tested by constraining the factor loadings across groups to assess if the factor loadings functioned
similarly for both high and low-risk drivers. The results reported no significant differences between the constrained and unconstrained configural models (see Table 6). Thus, the factors were perceived to function similarly for both high and low-risk young driver participants.

Table 7  
**Configural and metric invariance across risky driving propensity.**

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$(df)</th>
<th>RMSEA (90% CI)</th>
<th>CFI</th>
<th>$\Delta \chi^2$</th>
<th>$\Delta$ df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>390.18(248)</td>
<td>.04 (.03 - .05)</td>
<td>.96</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Model B</td>
<td>394.87(261)</td>
<td>.04 (.03 - .05)</td>
<td>.96</td>
<td>4.69</td>
<td>13</td>
</tr>
</tbody>
</table>

*Note. Model A = Configural, unconstrained model, Model B = Factor loadings invariant, $\chi^2 =$ Chi-Square; df = Degrees of Freedom; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; $\chi^2$ diff = Chi-Square Difference Test.*

**Adopter type invariance**

Last, invariance tests were conducted for likely and unlikely novel app adopter groups. A baseline model was established to examine model fit for both groups separately. Fit was reported as excellent for both likely adopters, $\chi^2_{(124, n = 197)} = 209.92; p < .001; Q = 1.69$; RMSEA = .06 (90% CI = .05 - .07); CFI = .96; AIC = 303.92, and unlikely adopters, $\chi^2_{(124, n = 136)} = 223.33; p < .001; Q = 1.80$; RMSEA = .08 (90% CI = .061 - .09); CFI = .93; AIC = 317.33.

Configural invariance was confirmed; $\chi^2_{(248)} = 433.36; p < .001; Q = 1.75$; RMSEA = .05 (90% CI = .04 - .06); CFI = .95; AIC = 621.36, and metric invariance was also reported, with no significant differences between the constrained and unconstrained configural models emerging (see Table 7). Thus, the factors were taken to function similarly for both likely and unlikely phone app adopters.
Table 8
Configural and metric invariance across adopter type.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$(df)</th>
<th>RMSEA (90% CI)</th>
<th>CFI</th>
<th>$\Delta \chi^2$</th>
<th>$\Delta$ df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>433.36(248)</td>
<td>$.05 (.04 - .06)</td>
<td>.95</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Model B</td>
<td>442.30(261)</td>
<td>$.05 (.04 - .05)</td>
<td>.95</td>
<td>9.04</td>
<td>13</td>
</tr>
</tbody>
</table>

Note. Model A = Configural, unconstrained model, Model B = Factor loadings invariant, $\chi^2$ = Chi-Square; df = Degrees of Freedom; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; $\chi^2$ diff = Chi-Square Difference Test.

Structural Equation Modeling

Structural paths were added to the measurement model (see Figure 8 below), and baseline model fit was assessed. Initial fit was ‘good’, $Q = 2.33$, RMSEA = .06 (90% CI = .05 - .07), CFI = .94 (see Table 8 below). Error covariances were added where they were suggested by the output, and deemed conceptually and theoretically appropriate. An error covariance was added between items on the perceived gains variable, the potential to gain cheaper insurance rates (item 4) and fewer costly penalty points (item 5). An error covariance was also added between items on the perceived risk variable, detailing the perceived risk of increasing their insurance premium (item 8), and the risk of being distracted by the app while driving (item 6). Both of these changes significantly improved model fit.

An examination of the modification indices and regression weights suggested two additional pathways within the model to improve this further. These were from delay discounting to perceived risks, and from perceived risks to perceived gains (see Figure 8). The addition of these new paths was considered in light of the available literature (discussed in greater detail in Section B2.7), and these were deemed theoretically meaningful. The final model demonstrated ‘excellent’ fit, $Q = 1.86$, RMSEA = .05 (90% CI = .04 - .06), CFI = .97, $\Delta$ AIC = 10.93, $p < .001$ (see Table 8), and accounted for 72.5% of the variance in BI (acceptance).
Figure 8. Revised SDSS acceptance model, with novel structural pathways highlighted.
Table 9  
Fit statistics of original and revised versions of the SDSS structural model.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$(df)</th>
<th>Q</th>
<th>RMSEA (90% CI)</th>
<th>CFI</th>
<th>AIC</th>
<th>$\Delta$ AIC</th>
<th>$\Delta \chi^2$</th>
<th>$\Delta$ df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline Model</td>
<td>328.92(141)</td>
<td>2.33</td>
<td>.06 (.05 - .07)</td>
<td>.94</td>
<td>426.92</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Covary e4-e5</td>
<td>289.55(140)</td>
<td>2.07</td>
<td>.06 (.05 - .07)</td>
<td>.96</td>
<td>389.55</td>
<td>37.36</td>
<td>39.36***</td>
<td>1</td>
</tr>
<tr>
<td>Covary e6-e8</td>
<td>277.50(139)</td>
<td>2.00</td>
<td>.06 (.05 - .06)</td>
<td>.96</td>
<td>379.50</td>
<td>10.05</td>
<td>12.05**</td>
<td>1</td>
</tr>
<tr>
<td>DelayD-&gt;PRisks</td>
<td>268.10(138)</td>
<td>1.94</td>
<td>.05 (.04 - .06)</td>
<td>.96</td>
<td>372.10</td>
<td>7.40</td>
<td>9.40**</td>
<td>1</td>
</tr>
<tr>
<td>PRisks-&gt;PGains</td>
<td>255.18(137)</td>
<td>1.86</td>
<td>.05 (.04 - .06)</td>
<td>.97</td>
<td>361.18</td>
<td>10.93</td>
<td>12.93***</td>
<td>1</td>
</tr>
</tbody>
</table>

Note. $\chi^2$ = Chi-Square; df = Degrees of Freedom; Q = Chi-Square/df Ratio; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; AIC = Akaike’s Information Criteria; $\Delta$ AIC = Delta Akaike’s Information Criteria; $\chi^2$ diff = Chi-Square Difference Test.
**Direct effects**

Consistent with hypotheses, higher perceived gains and higher social influence both predicted higher levels of BI (see Table 9). Higher perceptions of risks were found to predict lower perceived gains, and higher social influence scores were found to predict higher scores on the perceived gains variable. Last, higher social influence was found to predict lower perceived risks scores, whereas higher tendency for delay discounting predicted greater perceptions of risk associated with SDSS usage.

Contrary to hypotheses, perceived usability and perceived risks had no effect on SDSS acceptance (BI). Furthermore, perceived usability and delay discounting had no effect on perceived gains, and perceived usability had no effect on perceived risks (see Table 9).

**Indirect Effects**

As the final model was structured with both perceived risks and gains potentially mediating the relationships between the social influence and perceived usability predictors, and model outcome (BI), a test for indirect effects was conducted. Given the addition of the pathway between perceived risks and gains, indirect effects between the social influence and perceived usability variables, and perceived gains (as mediated by perceived risks), were also examined. This was executed using a Monte Carlo bootstrap, an optimal approach when assessing indirect effects using AMOS (Kline, 2011).

Two indirect effects on BI emerged as significant (see Table 9). Both perceived risks and social influence as mediated by perceived gains were significant predictors of BI outcomes. Social influence, perceived usability and delay discounting (as mediated by perceived risks) were all found to have significant indirect effects on the perceived gains variable. No other significant effects were observed.
Table 10
Standardised and unstandardised regression weights (with standard errors) for direct and indirect structural pathways in the SDSS acceptance model.

<table>
<thead>
<tr>
<th>Pathway</th>
<th>β</th>
<th>B</th>
<th>SE</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Direct effects on BI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BI &lt;= Perceived gains</td>
<td>.36</td>
<td>.55</td>
<td>.10</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Perceived risks</td>
<td>-.01</td>
<td>-.01</td>
<td>.09</td>
<td>.89</td>
</tr>
<tr>
<td>Social influence</td>
<td>.53</td>
<td>.82</td>
<td>.11</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Perceived usability</td>
<td>.07</td>
<td>.16</td>
<td>.10</td>
<td>.10</td>
</tr>
<tr>
<td>R² = 0.725</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Direct effects on perceived gains</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG &lt;= Perceived risks</td>
<td>-.26</td>
<td>-.27</td>
<td>.08</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Social influence</td>
<td>.55</td>
<td>.57</td>
<td>.08</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Perceived usability</td>
<td>.05</td>
<td>.07</td>
<td>.08</td>
<td>.39</td>
</tr>
<tr>
<td>Delay discounting</td>
<td>-.03</td>
<td>-.03</td>
<td>.04</td>
<td>.55</td>
</tr>
<tr>
<td><strong>Direct effects on perceived risks</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PR &lt;= Social influence</td>
<td>-.50</td>
<td>-.50</td>
<td>.08</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Perceived usability</td>
<td>-.27</td>
<td>-.38</td>
<td>.10</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Delay discounting</td>
<td>.16</td>
<td>.15</td>
<td>.05</td>
<td>.003</td>
</tr>
<tr>
<td><strong>Indirect effects on BI</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BI &lt;= Perceived gains &lt;= Perceived risks</td>
<td>-.09</td>
<td>-.15</td>
<td>.03</td>
<td>.001</td>
</tr>
<tr>
<td>Social influence</td>
<td>.25</td>
<td>.39</td>
<td>.05</td>
<td>.001</td>
</tr>
<tr>
<td>Perceived usability</td>
<td>.04</td>
<td>.10</td>
<td>.03</td>
<td>.07</td>
</tr>
<tr>
<td>Delay discounting</td>
<td>-.03</td>
<td>-.04</td>
<td>.02</td>
<td>.14</td>
</tr>
<tr>
<td><strong>Indirect effects on perceived gains</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PG &lt;= Perceived risks &lt;= Social influence</td>
<td>.13</td>
<td>.14</td>
<td>.04</td>
<td>.001</td>
</tr>
<tr>
<td>Perceived usability</td>
<td>.07</td>
<td>.10</td>
<td>.03</td>
<td>.001</td>
</tr>
<tr>
<td>Delay discounting</td>
<td>-.04</td>
<td>-.04</td>
<td>.02</td>
<td>.002</td>
</tr>
</tbody>
</table>
Structural model invariance tests

As when conducting the measurement model tests, the structural model was also subject to multi-group analyses to assess invariance, using the same three participant
groupings (i.e. males versus females, high versus low-risk drivers and likely versus unlikely adopters).

**Gender invariance**

In assessing gender invariance for the structural model, first, model fit was assessed for both groups separately. Males reported excellent fit, $\chi^2 (137, n = 113) = 170.85; p = .03; Q = 1.25; \text{RMSEA} = .05 (90\% \text{ CI} = .02 - .07); \text{CFI} = .97; \text{AIC} = 276.85$, and the model accounted for 73.9% of the variance in male BI, 53.9% in perceived gains and 24.4% in perceived risks. Excellent fit was also reported for females, $\chi^2 (137, n = 220) = 251.04; p < .001; Q = 1.83; \text{RMSEA} = .06 (90\% \text{ CI} = .05 - .07); \text{CFI} = .95; \text{AIC} = 357.04$, and the model accounted for 72.1% of the variance in female BI, 55.2% of the variance in perceived gains and 57.3% of the variance in perceived risks. Configural invariance (i.e. testing the model while allowing parameters to be estimated freely for males and females) was also achieved, $\chi^2 (274) = 422.01; p < .001; Q = 1.54; \text{RMSEA} = .04 (90\% \text{ CI} = .03 - .05); \text{CFI} = .96; \text{AIC} = 634.01$.

Following this, factor loadings (measurement weights) were constrained to be equal, and fit compared to the configural model. No significant chi-square difference was reported, and thus, factor loadings were interpreted to be equal across gender for the structural model. Structural pathways were then constrained to be equivalent, and invariance, as indicated by the non-significant difference in chi square change scores was reported, attesting that overall, the models for male and female young drivers did not differ significantly (see Table 10).

While the model performed similarly for both males and females, a number of gender differences in structural pathways were still observed. Perceived risk scores were found to significantly predict participant perceptions of gains for females ($\beta = -.33, p = .001$), but not for males ($\beta = -.21, p = .15$). Likewise, perceived usability scores significantly predicted perceptions of risk associated with use for women ($\beta = -.57, p < .001$), but not men ($\beta = -.21, p = .18$). In addition, delay discounting scores significantly predicted perceived risks for females ($\beta = -.14, p = .01$), but not males ($\beta = -.12, p = .15$). Pairwise comparisons were then conducted to assess if these differences were significant, by constraining the pathway for females, and then males in the multi-group model, and comparing the difference in chi square values, to assess if this was significant at df = 1. Only the pathway between perceived usability and perceived risks was found to differ significantly between the groups ($p < .05$).
Table 11
Factorial and structural invariance tests across gender.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$(df)</th>
<th>Q</th>
<th>RMSEA (90% CI)</th>
<th>$\Delta$ AIC</th>
<th>$\Delta \chi^2$</th>
<th>$\Delta$df</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>422.01(274)</td>
<td>1.54</td>
<td>.04 (.03 - .05)</td>
<td>.96</td>
<td>634.01</td>
<td>-</td>
</tr>
<tr>
<td>Model B</td>
<td>441.98(287)</td>
<td>1.54</td>
<td>.04 (.03 - .05)</td>
<td>.95</td>
<td>627.98</td>
<td>6.03</td>
</tr>
<tr>
<td>Model C</td>
<td>458.49(298)</td>
<td>1.54</td>
<td>.04 (.03 - .05)</td>
<td>.95</td>
<td>622.49</td>
<td>5.49</td>
</tr>
</tbody>
</table>

Note. Model A = Configural model, Model B = Measurement weights constrained, Model C = Structural weights constrained, $\chi^2$ = Chi-Square; df = Degrees of Freedom; Q = Chi-Square/df Ratio; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; AIC = Akaike’s Information Criteria; $\Delta$ AIC = Delta Akaike’s Information Criteria; $\chi^2$ diff = Chi-Square Difference Test.

Risky driving propensity invariance

In assessing risky driving propensity (i.e. high or low-risk drivers) invariance for the structural model, first, model fit was assessed for both high and low-risk driving groups separately. High-risk drivers reported excellent fit, $\chi^2(137, n = 175) = 216.62; p < .001; Q = 1.58; RMSEA = .06 (90% CI = .04 - .07); CFI = .95; AIC = 322.62$, and the model accounted for 63.7% of the variance in their BI to adopt, 55.3% in perceived gains and 45.1% in perceived risks. Excellent fit was also reported for low-risk drivers, $\chi^2(137, n = 158) = 196.60; p = .001; Q = 1.44; RMSEA = .05 (90% CI = .04 - .07); CFI = .964; AIC = 302.60$, and the model explained 83.1% of the variance in their BI, to 58.9% of the variance in perceived gains and 39.6% of the variance in perceived risks associated with use. Configural invariance was also achieved, $\chi^2(274) = 413.22; p < .001; Q = 1.51; RMSEA = .04 (90% CI = .03 - .05); CFI = .96; AIC = 625.22$.

Following this, factor loadings were constrained to be equal, and fit compared to that of the configural model. No significant difference in chi-square values was reported, and thus, factor loadings were deemed to be equal across risky driving propensity for the structural model (see Table 11). Structural pathways were then constrained to be equal, and again, invariance, as indicated by the non-significant difference in chi square change scores was reported, attesting that overall, the models for high and low-risk drivers functioned in the same way.

While the model performed similarly for both high and low-risk drivers, a number of differences in structural pathways were still observed. For high-risk drivers, the pathway
between delay discounting and perceived risks was significant ($\beta = .22, p < .001$), but for low-risk drivers this was not the case ($\beta = -.01, p = .96$). Likewise, perceptions of usability predicted perceived gains scores for high-risk drivers ($\beta = .24, p = .03$), but not low-risk participants ($\beta = -.17, p = .22$). In addition, the pathway between perceived usability to BI for low-risk drivers was significant ($\beta = .30, p = .048$), but was not for the high-risk group ($\beta = .15, p = .29$). Significant differences only emerged for the pathways between delay discounting and perceived risks ($p < .05$), and perceived usability and perceived gains however ($p < .05$).

Table 12
Factorial and structural invariance tests across risky driving propensity.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$(df)</th>
<th>Q</th>
<th>RMSEA (90% CI)</th>
<th>CFI</th>
<th>AIC</th>
<th>$\Delta$ AIC</th>
<th>$\Delta \chi^2$</th>
<th>$\Delta \text{df}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>413.22(274)</td>
<td>1.51</td>
<td>0.04 (.03 - .05)</td>
<td>.96</td>
<td>625.22</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Model B</td>
<td>418.22(287)</td>
<td>1.46</td>
<td>0.04 (.03 - .05)</td>
<td>.96</td>
<td>604.22</td>
<td>21.01</td>
<td>4.99</td>
<td>13</td>
</tr>
<tr>
<td>Model C</td>
<td>436.23(298)</td>
<td>1.46</td>
<td>0.04 (.03 - .05)</td>
<td>.96</td>
<td>600.23</td>
<td>3.99</td>
<td>18.02</td>
<td>11</td>
</tr>
</tbody>
</table>

Note. Model A = Configural model, Model B = Measurement weights constrained, Model C = Structural weights constrained, $\chi^2$ = Chi-Square; df = Degrees of Freedom; Q = Chi-Square/df Ratio; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; AIC = Akaike’s Information Criteria; $\Delta$ AIC = Delta Akaike’s Information Criteria; $\chi^2$ diff = Chi-Square Difference Test.

Adopter type invariance

In assessing adopter type invariance for the structural model, first, model fit was assessed for both groups separately. Likely adopters reported excellent fit, $\chi^2 (137, n= 197) = 219.20; p < .001; Q = 1.60; \text{RMSEA} = .06 (90\% \text{ CI} = .04 - .07); \text{CFI} = .96; \text{AIC} = 325.20$, and the model accounted for 70.7% of the variance in likely adopter BI to adopt, 53.9% of the variance in perceived gains, and 27.9% in perceived risks. Excellent fit was also reported for unlikely adopters, $\chi^2 (137, n = 136) = 225.97; p < .001; Q = 1.65; \text{RMSEA} = .07 (90\% \text{ CI} = .05 - .09); \text{CFI} = .94; \text{AIC} = 331.97$, and the model accounted for 75.9% of the variance in their BI, 61.6% of the variance in perceived gains and 61% of the variance in perceived risks. Configural invariance was also achieved, $\chi^2 (274) = 445.28; p < .001; Q = 1.63; \text{RMSEA} = .04 (90\% \text{ CI} = .04 - .05); \text{CFI} = .95; \text{AIC} = 657.28$.

Following this, once again, factor loadings were constrained to be equal, and fit compared to the configural model. No significant chi-square difference was reported, and
thus, factor loadings were determined to be equal across adoption likelihood for the structural model. Structural pathways were then constrained to be equal, and invariance, as indicated by the non-significant difference in chi-square change scores was reported, attesting that overall, the models for unlikely and likely phone app adopters did not differ significantly (see Table 12).

While the model performed similarly for both unlikely and likely adopters, a number of differences in structural pathways were again observed. Perceived usability had a significant effect on perceived risks for likely adopters ($\beta = -.54, p = .006$), but not unlikely participants ($\beta = -.10, p = .46$). Perceived risks was also found to have a significant effect on perceived gains for likely adopters ($\beta = -.36, p < .001$), but not unlikely adopting participants ($\beta = -.06, p = .69$). Delay discounting was also a significant predictor of perceived risks for the unlikely adopter group ($\beta = -.21, p = .003$), but not for those in the likely adoption group ($\beta = -.12, p = .08$). None of these emerged as statistically significant differences however.

Table 13
Factorial and structural invariance tests across adopter type.

<table>
<thead>
<tr>
<th>Model</th>
<th>$\chi^2$(df)</th>
<th>Q</th>
<th>RMSEA (90% CI)</th>
<th>CFI</th>
<th>AIC</th>
<th>$\Delta$ AIC</th>
<th>$\Delta\chi^2$</th>
<th>$\Delta df$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model A</td>
<td>445.28(274)</td>
<td>1.63</td>
<td>.04 (.04 - .05)</td>
<td>.95</td>
<td>657.28</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Model B</td>
<td>454.98(287)</td>
<td>1.59</td>
<td>.04 (.04 - .05)</td>
<td>.95</td>
<td>640.98</td>
<td>16.30</td>
<td>9.7</td>
<td>13</td>
</tr>
<tr>
<td>Model C</td>
<td>469.61(298)</td>
<td>1.58</td>
<td>.04 (.03 - .05)</td>
<td>.95</td>
<td>633.61</td>
<td>7.37</td>
<td>4.63</td>
<td>11</td>
</tr>
</tbody>
</table>

Note. Model A = Configural model, Model B = Measurement weights constrained, Model C = Structural weights constrained, $\chi^2$ = Chi-Square; df = Degrees of Freedom; Q = Chi-Square/df Ratio; RMSEA = Root Mean Square Error of Approximation; CFI = Comparative Fit Index; AIC = Akaike’s Information Criteria; $\Delta$ AIC = Delta Akaike’s Information Criteria; $\chi^2$ diff = Chi-Square Difference Test.

Examining SDSS adoption

As stated, given the uneven distribution of the binary adoption scores (this was approximately 90% ‘no, 10% ‘yes’), this measure could not be included as an outcome variable for the SEM analysis (Byrne, 2010). It was then decided to alternatively predict adoption scores using logistic regression. Upon conducting this analysis however, although a number of the predictors (e.g. perceived gains) significantly improved the ability to classify or predict non-adopters, at no point did it correctly predict any of the adopting participants,
consistently misclassifying them. This indicated that logistic regression was not an appropriate analysis for this data set, and that there were underlying issues with the adoption measure.

Given that a logistic regression could not be conducted due to the nature of the distribution, Mann-Whitney U tests were employed to test for significant differences amongst the predictor variables for the adopting and non-adopting participants. Two were identified. Behavioural intention differed significantly for adopters \((Mdn = 17)\) versus non-adopters \((Mdn = 16)\), \(U = 3398, z = -2.33, p = .02, r = -.13\). Perceived usability was also found to differ significantly between adopting \((Mdn = 8)\) and non-adopting \((Mdn = 7)\) groups, \(U = 3195, z = -2.73, p = .006, r = -.15\).

**B2.6 Discussion**

*Overview*

Overall, perceived gains and social influence variables emerged as significant, direct predictors of young driver acceptance of SDSS technology. Significant indirect effects of perceived risks and social influence (as mediated by perceived gains) on BI were also observed. Both measurement and structural models provided an excellent fit to the data (Byrne, 2010), and the final structural model accounted for 72.5% of the outcome variance in acceptance. Multi-group invariance (across gender, risky driving propensity and adopted type) was also observed during both the CFA and SEM analyses, attesting to the ‘conceptual soundness’ of the proposed measurement and structural models and constructs (Schreiber et al., 2006, p. 335). Also, of note, 58% of young drivers reported that they agreed, or strongly agreed that they ‘want to use this app’, and 47% agreed or strongly agreed that they ‘intend to use’ this kind of technology in future.

*Supported direct effects*

Specifically, four direct pathways influencing BI were hypothesised and tested, of which two were supported empirically. Perceived gains and social influence were found to have significant, direct effects on BI, but perceived risks and perceived usability did not predict the acceptance outcome measure. The significant finding for perceived gains, with young drivers scoring highly on this variable reporting greater intention to adopt this novel technology, highlights the importance that young drivers attribute to the perceived benefits of using a monitoring app. This resonates with the conclusions reached in the earlier acceptability systematic review (Study 1, Chapter 3), including the host of qualitative young
driver studies which have suggested that the potential benefits of monitoring (e.g. receipt of insurance discounts, driving improvements etc.) are highly influential for acceptance and adoption decisions (e.g. Lerner et al., 2010; K. L. Young et al., 2003b). It is also in line with the documented central role of similar gains-related constructs in TA models throughout the empirical literature (e.g. see Davis, 1989; Venkatesh et al., 2003, 2012). Likewise, the significant finding for social influence supports the importance of social approval in shaping young driver decision-making (in this case, forming an intention to use a SDSS), which has been documented throughout the broader psychological research literature (e.g. regarding engaging in sexual activity, Fearon, Wiggins, Pettifor, & Hargreaves, 2015; decisions to smoke, Su et al., 2015; or food choices and weight, J. Zhang et al., 2015). This finding also mirrors previous TA study results, which point to the need to incorporate social influence variables in structural TA models (e.g. Venkatesh & Davis, 2000; Venkatesh et al., 2003; 2012).

Social influence, perceived usability and delay discounting were also hypothesised to have direct effects on perceived gains and risks, with perceived risks then also anticipated to have a direct effect on perceived gains. Results of the current study supported the majority of these pathways. In terms of direct effects on perceived gains, both perceived risks and social influence had a significant effect on this variable. That is, greater perceived risks (including potential for distraction, or increased insurance premiums with SDSS usage) predicted lower perceived gains or benefits of use for young drivers. Higher perceptions of SDSS approval by peers, friends, and family predicted higher young driver perceived gains.

In examining the perceived risks construct, social influence and delay discounting were found to have significant direct effects on this variable. Regarding social influence, this again suggests that young driver perceptions of risks associated with SDSS use derive, in part, from the perceived attitudes of those close to them. In understanding the delay discounting finding, extensive research has documented that a higher tendency for delay discounting is associated with engagement in a number of high-risk behaviours (e.g. risky sexual behaviours, Dariotis & Johnson, 2015; or drug and alcohol abuse, Stanger et al., 2012). It is likely that more impulsive young drivers anticipate greater risks with their using a SDSS (e.g. relating to increases in insurance premiums).

**Supported indirect effects**

A series of indirect effects were also proposed and tested within the structural model. Two significant indirect pathways to BI emerged from the four hypothesised. First, the social influence - BI relationship was mediated by perceived gains. Second, the perceived risks - BI
relationship was also mediated by perceived gains. Once more, this attests to the importance of the perceived gains construct in shaping young driver intention to adopt SDSSs. Last, social influence, perceived usability and delay discounting were all found to have significant, indirect effects on perceived gains, as mediated by perceived risks. Again, these findings highlight the important role of social influence, with its having both direct and indirect effects on BI, and the role of perceived risks in influencing gains associated with SDSS monitoring.

Such findings, and those in relation to the factors having significant, direct effects on BI, are of relevance to key stakeholders, such as SDSS providers, insurance companies or road safety bodies, who may, upon evidence that SDSSs can improve young driver safety, seek to promote their use. These results would suggest that persuasive communication and advertising campaigns which focus on outlining the perceived benefits or gains to driving with SDSS technology, while minimising the associated risks, for example, will prove most effective in enhancing SDSS acceptance. Similarly, enhancing the perception that fellow young drivers are in favour of SDSS usage (i.e. harnessing social influence) may be influential in increasing SDSS use likelihood.

**Null effects**

Contrary to hypotheses, neither perceived risks nor perceived usability were found to have significant, direct effects on BI. Perceived usability also did not have a direct effect on perceived risks. It is likely that this can be attributed, at least in part, to the fact that drivers in this study have no direct experience of using SDSS, and that such effects may only become pertinent with experience. Data would also suggest some evidence of a ceiling effect for the perceived usability construct, wherein young drivers, an age group with high levels of regular app use and app-related self-efficacy (Purcell, Entner, & Henderson, 2010), reported high levels of SDSS perceived usability overall (mean score/\( M = 15.95, SD = 12.51 \), with a total score range of 4-20), resulting in less predictive utility for this construct.

In addition, no significant effects of delay discounting and perceived usability on perceived gains were reported. That delay discounting did not have a significant indirect effect on perceived gains was unexpected, however it did have a significant indirect effect on perceived gains as mediated by perceived risks. Accordingly, non-significant indirect effects of perceived usability and delay discounting on BI as mediated by perceived gains were also observed.

**Model modifications**

It is also important to consider the modifications made to the model that was initially proposed. The development of novel theories and models commonly involves a process of
refinement based on theory and data-informed modifications (Byrne, 2010). During the analyses reported here, a number of such modifications were made. First, perceived accuracy and attitudes were not retained as distinct factors following the initial EFA and parallel analysis. Aspects of perceived accuracy, for instance, may have already been captured by the factors that emerged from the analyses. It has conceptual similarities to perceptions of risks (e.g. the risk of distraction from inaccurate warnings) and perceived usability (a perceived inaccurate device may be more difficult to use). The perceived accuracy item “I could depend on this app to work reliably”, for example, was retained as a perceived gains variable following the EFA. In addition, the value of including ‘attitudes’ in models of intention has been long-questioned, with Venkatesh et al. (2003) arguing that any observed relationship between attitude and intention (in a TA context) is likely to be spurious, and resulting from the omission of other key predictors such as performance expectancy (in this case, perceived gains) and effort expectancies (or, perceived usability). In this case, an examination of the EFA analysis revealed that all three of the attitudes items loaded on to the perceived gains factor. These were not retained following the CFA however.

A second refinement to the model involved the addition of two new structural pathways during the initial SEM analysis - from delay discounting to perceived risks, and from perceived risks to perceived gains. While not proposed a-priori, they can be justified. With regards to the pathway between delay discounting and perceived risks, as previously stated, evidence suggests that more impulsive young drivers (i.e. those with higher tendencies for delay discounting) may perceive themselves as more likely to experience SDSS risks (such as an increased insurance premium). This is due to their heightened overall tendency to engage in risky behaviours. This path was not initially proposed, as a more parsimonious model was sought, and to avoid specifying an overly complex structure. This was also the case in relation to the perceived risks - perceived gains pathway. Regarding this relationship, following the SEM analyses and consulting literature in relation to decision-making, risk/gains ratios and TA (e.g. Featherman & Pavlou, 2003; Luo, Li, Zhang, & Shim, 2010; J. Scott, 2000), wherein perceived risks have been found to relate to perceptions of related benefits, it seems reasonable to hypothesise that perceptions of SDSS risks can influence perceptions of gains. An individual who believes that a SDSS may distract them from driving, or potentially increase their insurance premium, for example, may naturally not be as inclined to perceive SDSS usage as resulting in safer, better driving, and insurance benefits. Higher perceived risks were indeed found to predict lower perceived gains (see Table 9).
Invariance tests

Last, it should be acknowledged that multi-group invariance across gender (males versus females), risky driving propensity (high versus low-risk drivers), and adoption likelihood (likely versus unlikely phone app adopters) was observed for the structural model, indicating that the model functioned similarly well for all participant groups. At the same time, a small number of significant path differences were observed. First, perceived usability scores were found to directly predict perceptions of risks for females, but not for males. This is in line with research suggesting that perceived usability or effort expectancy factors may be more salient for women than men (e.g. Venkatesh & Morris, 2000); for example, women frequently report greater levels of technology use-related anxiety than males (Emmons, 2003; Hong & Koh, 2002).

Second, for high-risk drivers only, delay discounting had a significant positive effect on perceived risks, and perceived usability had a significant positive effect on perceived gains. In looking at delay discounting in relation to perceived risks, the finding that high-risk and impulsive drivers (i.e. those with higher tendencies for delay discounting) would report greater perceptions of risk associated with SDSS use lends further support to our rationale for the pathway between delay discounting and perceived risks. That is, that riskier and more impulsive young drivers perceive a greater likelihood of potential negative consequences (such as increases in their insurance premium) when considering adopting a road safety app. High-risk drivers also often have an optimism bias, wherein they perceive their skills to be greater than they objectively are (White et al., 2011). Thus, it is possible that high-risk drivers associate their perceived high skill at using and driving with the app as linked to their high likelihood of receiving gains, resulting in a more significant influence of perceived usability on perceived gains.

Limitations

There were a number of limitations to the current study, and implications from this work must be considered in light of these. One concern relates to sample representativeness, with the achieved sample being primarily in third-level education (87%), and female (66%). While sample representativeness is not an uncommon issue in psychological research (e.g. Gallander Wintre, North, & Sugar, 2001), it can have an impact on the predicative utility of the model when applied to a more representative sample of drivers who use smartphones. With a student dominant sample, for example, factors associated with socioeconomic status may potentially influence findings. Future research should strive to replicate these results using a more balanced, nationally representative sample. A second limitation of the study
related to the inability to draw on the adoption measure in our analyses. The relationship between intention and action is, at times, tenuous (e.g. see Amireault, Godin, Vohl, & Perusse, 2008; Sheeran, 2002) and although Mann-Whitney U analyses indicated that adopting and non-adoption participants differed in terms of their perceived usability and BI scores (in line with findings in relation to the TPB, e.g. Truong, 2009) ultimately, future studies should strive to incorporate a more sensitive measure of adoption such that a more detailed picture of intention to use, and how this relates to actual SDSS adoption can be provided.

**B2.7 Contribution**

Overall, the findings from this study have extended the TA and driver monitoring research literatures, and provided a novel, structural model with ‘excellent fit’ and theory of SDSS acceptance for future research use. Such findings also lend support to calls to consider context-specific models of technology acceptance in order to maximise explanatory potential (e.g. Kaasinen et al., 2011). Results here can be of relevance when applied to the work of advertising companies, such as those working for SDSS manufacturers and providers (e.g. road safety bodies or insurers). An emphasis on promoting positive perceptions of peer usage, to enhance social influence, could prove a promising approach to enhance young driver adoption rates, for example. Last, this study has also provided an initial indicator as to how acceptable SDSSs are considered by young drivers for use (e.g. 58% agreed or strongly agreed that they ‘want to use this app’), and an established measure to assess SDSS acceptance in future empirical studies.

**B2.8 Conclusions**

The current study proposed a novel structural model of SDSS acceptance. Overall, the model provided excellent fit to the data, demonstrated multi-group invariance and accounted for 72.5% of the variance in BI. This attests to its value in predicting and understanding young driver acceptance of SDSSs. The significant influences of perceived gains and social influence on BI may inform applications manufacturers, insurance companies, advertisers, and road safety bodies as to how to maximise future SDSS uptake and use, potentially reducing young driver RTC fatality and injury rates. The current study also extends the existing TA literature by highlighting the roles of a number of factors not typically investigated, such as delayed discounting and perceived risks. Although this model must be
tested with additional samples, and a more sensitive measure of adoption is required, the results attest to the robustness of the model and value of this theory in understanding young driver SDSS acceptance.
Section B3: Interim Summary - SDSS Acceptance

In considering the findings of Section B, the following points can be noted. First, a series of established and more novel, context-specific TA factors have emerged as influencing SDSS acceptance from the findings of the systematic review study, and SEM analysis, in both direct and indirect ways. In particular, the importance of the perceived benefits or gains to using SDSS technology, and the crucial role of peers in shaping acceptance of in-vehicle monitoring have been acknowledged. Having tested and established this theoretical structure of young driver SDSS acceptance, this model, built on the findings of the systematic review, can now be used as a tool to examine and predict acceptance of any novel configurations of SDSS features, while highlighting key areas to target to potentially maximise uptake. In all, findings from Studies 1 and 2 suggest promising levels of young driver acceptance of typical SDSSs in Ireland at present, such that targeting identified influential factors (e.g. highlighting the gains associated with use) could potentially result in large scale adoption if made available and advertised nationwide.

Certain questions regarding the topic of young driver SDSS acceptance and adoption do remain. The findings of the systematic review and SEM acceptance studies, for example, primarily established a series of key factors influencing intention to use SDSSs, but those impacting on adoption remain to be empirically identified. It is also not yet clear whether acceptance may influence the efficacy of young driver SDSS implementation (and vice versa). A young driver, opposed to the concept of monitoring may be less inclined to observe corrective real-time feedback, or adhere to suggested post-journey strategies to improve driving. Although examining variation in SDSS acceptance or adoption over time/experience is outside the scope of the current programme of research, the impact of initial acceptance of a SDSS device when first driving with one should, and can, be examined within this thesis.

Last, it is important to note that, while the findings of Section B suggest high levels of young driver SDSS acceptance, and likely, usage, it is necessary to ensure they are effective in evoking positive driving-related behaviour change before their use should be promoted, or featured in ways to maximise uptake. Section C will endeavour to assess this.
Section C - Efficacy: Does the implementation of SDSSs reduce risky driving behaviours in young drivers?

Overview
This section seeks to examine whether SDSSs are effective in reducing young driver risk-taking (see Figure 9). In order to do so, it first reports on the findings of a comprehensive systematic review, which aimed to establish an evidence base on the topic of IVDR efficacy in the context of young driver usage (Section C.1, Study 3). Following this, a brief series of studies (Section C.2, Studies 4a + 4b) were conducted to evaluate the novel driving simulator obtained to conduct SDSS efficacy research as part of the current programme of research. Once the suitability of the simulator was confirmed, a study investigating the impact of SDSS monitoring on young driver speed, and potential moderators of this effect was conducted (Section C.3, Study 5). Building from these findings, a study assessing the impact of real-time, visual SDSS feedback, a financial incentive, and a combined financial incentive and real-time, visual SDSS feedback was then completed (Section C.4, Study 6). A summary of the overall research findings of this efficacy section is then provided (Section C.5).

Figure 9. Overview of the four studies of Section C - Efficacy.
Chapter 5 - Section C1: A Systematic Review of Young Driver Monitoring Efficacy Research: 2003 - 2013

C1.1 Abstract

**Background:** While young drivers may accept SDSSs, in order for their use and continued development to be justified, they must be effective in evoking positive behavioural change. Within the broader IVDR literature, studies on this topic have typically featured varying outcome measures, and methodological approaches. As such, it is unclear how effective in-vehicle monitors are in a young driver context, or what theory and factors underpin effectiveness.

**Aims:** The aims of this study were: 1) To synthesise findings on the effects of young driver engagement with an in-vehicle monitoring device, and; 2) Identify the mechanisms underlying effectiveness, and that can be used in the design of subsequent studies.

**Methodology:** A systematic review of the young driver IVDR efficacy literature was conducted. Five electronic databases were searched using specified key words (e.g. ‘teen driver’, and ‘advanced driver assistance system’), and hand searches of academic journals were conducted. Narrative synthesis was employed to analyse the studies extracted, as sufficient detail was not present to conduct a meta-analysis.

**Findings:** Eight studies (quantitative, and typically of low quality) were extracted for the narrative synthesis. Overall, young driver IVDR use was found to decrease extreme manoeuvres, and reduce driver speed. Coded Behaviour Change Techniques (BCTs) indicated that Self-Regulation (SR) and Operant Conditioning (OC) theory and processes likely underlie SDSS and IVDR efficacy.

**Conclusions:** Given the conceptual similarities between IVDR and SDSS technology, it is anticipated that SDSS use will have a similar positive influence on young driver behaviour, through similar mechanisms, although this has yet to be empirically demonstrated. Of note, certain unique characteristics are retained by SDSSs (e.g. they cannot physically intervene to limit speed) such that SDSS specific investigations are warranted for definitive findings on this topic at this stage.

**Implications:** These findings suggest SDSSs will likely improve young driver behaviour, and provide evidence to inform the design of SDSS and young driver-specific efficacy studies to be tested in Studies 5 and 6.
C1.2 Introduction

This chapter presents a systematic review of empirical research on the impact of young driver monitoring on risky driving (Study 3). The review addressed two key questions for this area of research: 1) Based on the evidence available, does driver monitoring reduce young driver risk-taking? and; 2) If so, what are the mechanisms of change that bring about this impact? Answers to these questions then informed the experimental research reported in the rest of this section (i.e. Section C - Efficacy). The review was completed concurrently with the systematic review of the monitoring acceptability literature (Study 1, Chapter 3). The current study also primarily involved reviewing the conceptually similar young driver IVDR literature in light of the specified research questions, given the dearth of SDSS-specific studies. Examining this material can provide an initial estimate as to how effective SDSSs may be, help identify the underlying theoretical mechanisms influencing their potential efficacy, and thus inform future empirical SDSS-specific research.

C1.3 Rationale for the current study

At present, SDSSs are being advertised and promoted to young driver users by both insurance companies and phone application providers worldwide, as cost-effective means of improving driver outcomes, reducing insurance premiums and increasing road safety. However, in the absence of definitive SDSS empirical research, it is unclear if, or to what extent, SDSSs are evidence-based and can deliver the intended benefits. This information is of key importance to stakeholders, to provide them with evidence as to whether future investment in SDSS development is warranted. It is also likely that the extent to which SDSSs are effective, may influence whether young drivers continue to use them following initial SDSS adoption. Moreover, if SDSSs do work, it is critical that there is an understanding of how they produce the desired effects (i.e. the mechanisms of change involved). Understanding the underlying mechanisms influencing SDSS efficacy can inform future design and SDSS research, so as to identify means to maximise their safety potential.

As such, the current chapter presents the results of the first systematic review of the young driver, monitoring efficacy, literature. Specifically, the systematic review methodology was employed to assess the efficacy of young driver, in-vehicle monitoring interventions (SDSSs or IVDRs), to inform estimates of how effective SDSSs may prove to be, and through what behaviour change techniques (BCTs) they may act. The specific review questions addressed were:
1. Does in-vehicle monitor use by young drivers lead to a reduction in risky driving?
2. What are the BCTs employed in these interventions?

**C1.4 Method**

*Systematic search procedure*

Reflecting the rapid advances in monitoring technology in the past decade alone, the review included research published during the period of 2003-2013 (with the aim of enhancing the validity of the findings). The electronic databases PsycINFO, ScienceDirect, Scopus, TRID (Transport Research International Documentation) and Web of Knowledge were selected for use, and a series of specified key search terms entered. For the current review, terms relating to impact (e.g. ‘efficacy’) were searched, in addition to, and in conjunction with, monitoring terms (e.g. ‘driver monitoring’, ‘in-vehicle data recorder’ etc.) and key participant phrases (e.g. ‘young driver’, ‘novice driver’). The terms were combined using operands AND/OR, with syntax varying depending on the search engines being utilised, and were selected based on an initial scoping review of the literature. Hand-searches were completed of applied, relevant journals such as Accident Analysis and Prevention, the Journal of Safety Research, Transportation Research Part F and Safety Science. The ‘References’ section from each selected research paper were also searched for any additional, potentially relevant study titles. Last, leading researchers in the area were contacted with requests for any potentially relevant studies recently accepted for publication or in press.

*Inclusion and exclusion criteria*

Given that IVDR use in a young driver context can still be considered an emerging topic of research, there is a relative absence of empirical efficacy studies on IVDR and SDSS monitoring of young drivers. Thus, the inclusion and exclusion criteria for this systematic review were deliberately broad. Relevant research studies, written in English and published between 2003-2013 were selected for inclusion. Studies had to feature experimental research, to include driving participants under the age of 25, and an in-vehicle monitoring device that gave real-time and/or post-journey feedback relating to a specified driving behaviour(s) to the young drivers and/or their parents/insurers.

*Data extraction and synthesis*

The PRISMA chart (Figure 10) and extraction table (Table 13) provide an overview of the quantity of papers screened, and excluded at, each phase of the review process. During this process, all articles were exported to an Endnote database, where the systematic search
process was managed. Eight final papers met all inclusion/exclusion criteria (see Table 13). In the absence of sufficient data to facilitate a meta-analysis, the results relating to the ‘efficacy’ review question were synthesised narratively. Guidance for narrative synthesis was taken primarily from Popay et al. (2006) and J. Thomas and Harden (2008).

The BCT taxonomy (v1) was used to code the BCTs coded in the monitoring interventions (Michie et al., 2013). A BCT is an ‘observable, replicable and irreducible component of an intervention designed to alter or redirect causal processes that regulate behavior; that is, a technique is proposed to be an ‘active ingredient’ (e.g., feedback, self-monitoring, reinforcement) in an intervention (Michie et al., 2013, p. 4). The taxonomy was created as a tool to facilitate the identification of active intervention components, research replication, implementation in practice, and synthesis in systematic reviews. Two coders (AK and RC) trained in BCT coding (via the BCTTv1 online training; http://www.bct-taxonomy.com/) independently coded all eight papers for BCTs (see Table 15). Inter-coder reliability was calculated using Prevalence and Bias Adjusted Kappa (PABAK; Byrt, Bishop, & Carlin, 1993). Good inter-coder reliability was reported (mean PABAK > 0.8). PABAK has been used in previous BCT coding research as it adjusts for high prevalence of negative agreement.

Quality assessment

The details of the quality assessment (adapted from Malik, Blake, & Suggs, 2014) of the eight efficacy studies are presented in full in Table 14. Three studies were RCTs, and the remaining five featured single-group, repeated measures designs. Seven of the eight studies described their method of recruitment, and half specifically outlined their eligibility criteria when recruiting participants. One RCT study reported similarities between their eligibility criteria baseline, and that investigators were blinded to condition assignment. Five of the studies reported attrition rates, with completion rates ranging from 50-100% of original participant numbers. None of the eight studies described the inclusion of non-randomised comparisons (i.e. purposefully selected comparison groups).
Records identified through database searching (n = 3110)

Additional records identified through other sources (n = 2)

Records after duplicates removed (n = 2130)

Titles screened (n = 2130)

Records excluded (n = 2062)

Abstracts screened (n = 68)

Records excluded: 30
Ineligible participant group (n = 3)
Not IVDR feedback research (n = 25)
Identical studies (different titles) (n = 2)

Full-text articles assessed for eligibility (n = 38)

Records excluded: 30
Ineligible participant group (n = 18)
Not IVDR feedback research (n = 12)

Studies included in narrative synthesis (n = 8)

Figure 10. PRISMA diagram outlining study selection procedures.
Table 14
Extracted efficacy studies from a systematic review of the young driver monitoring literature.

<table>
<thead>
<tr>
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<tbody>
<tr>
<td><strong>Objective</strong></td>
<td>To evaluate how young drivers drive three years after licensure with IVDR feedback.</td>
<td>To test the effects of Pay-As-You-Drive insurance, and IVDR monitoring and feedback on young driver speed.</td>
<td>To determine if in-vehicle monitoring with real-time and post-journey feedback (including parental reports) would improve driving behaviour.</td>
</tr>
<tr>
<td><strong>Sample Characteristics</strong></td>
<td>N = 32</td>
<td>N = 141</td>
<td>N = 18 (included in final analysis)</td>
</tr>
<tr>
<td>Mean age = 20.5 (SD = *), Age range = *</td>
<td>60% (n = 85) M, 40% (n = 56) F Mean Age = 24.4 (SD = 2.2) Age Range = *</td>
<td>39% (n = 7) M, 61% (n = 11) F Mean Age = 16 (SD = *) Age Range = *</td>
<td>94% (n = 15) M, 6% (n = 1) F Age = 18-19 (SD = *) Age Range = 18-19 years</td>
</tr>
<tr>
<td><strong>Design Description</strong></td>
<td>Single group, pre-post test design.</td>
<td>Between subjects design. Group 1 = Gain Incentive, Group 2 = Loss Incentive, Group 3 = Control. Groups 1 and 2 were later combined for the purpose of data analysis.</td>
<td>Single group, pre-post test design.</td>
</tr>
<tr>
<td><strong>Results</strong></td>
<td>Feedback resulted in reductions of safety-related events, however no significant decreases were reported.</td>
<td>Significant speeding reductions (from 18.6% - 17.6%) reported within the treatment group, and reductions relative to control participants recorded.</td>
<td>Reduction of 61% in ‘coachable’ driving events.</td>
</tr>
<tr>
<td><strong>Type of Monitor Device</strong></td>
<td>GreenRoad IVDR</td>
<td>In-vehicle GPS Device.</td>
<td>DriveCam IVDR</td>
</tr>
<tr>
<td><strong>Functionality</strong></td>
<td>Measured braking, acceleration, turns, lane handling and speed. Provided continuous real-time visual feedback (green, red or amber LEDs) and post-journey online reports.</td>
<td>Measured speed, mileage, extent of night and day-time driving and day of the week. Provided post-journey feedback via online reports.</td>
<td>Recorded video of and measured ‘coachable events’ related to g-force violations including crashes, hard braking and acceleration, hard turning and cornering. Provided real-time visual feedback (blinking red LED when unsafe event occurred). Also provided post-journey feedback online and via weekly parental reports including DVD footage.</td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Israel</td>
<td>The Netherlands</td>
<td>USA</td>
</tr>
</tbody>
</table>
Table 13. Extracted ‘effectiveness’ studies from a systematic review of the young driver monitoring literature (cont’d).

<table>
<thead>
<tr>
<th></th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Objective</strong></td>
<td>To determine if in-vehicle monitoring with real-time and post-journey feedback (including parental reports) would improve driving behaviour.</td>
<td>To determine if in-vehicle monitoring with real-time and post-journey feedback (including parental reports) would improve driving behaviour.</td>
<td>To determine if in-vehicle monitoring with real-time and post-journey feedback (including parental reports) would improve driving behaviour.</td>
<td>To compare the impact of real-time feedback, versus real-time, post-journey and parental feedback upon driver behaviour.</td>
</tr>
<tr>
<td><strong>Sample Characteristics</strong></td>
<td>N = 84 45% (n = 38) M, 55% (n = 46) F Mean Age = * (SD = *) Age Range= 16-17 years</td>
<td>N = 26 46% (n = 12) M, 54% (n =14) F Mean Age = * (SD = *) Age Range = 16-17 years</td>
<td>N = 32 46% (n = 14) M, 56% (n = 18) F Mean Age = * (SD = *) Age Range = 16-17 years</td>
<td>N = 88 52% (n = 46) M, 48% (n = 42) F Mean Age = 16.4 (SD = *) Age Range = &lt;18 years.</td>
</tr>
<tr>
<td><strong>Design Description</strong></td>
<td>Between subjects design (RCT). Group 1 = Real-time alert and parental website notification. Group 2 = Real-time alert and conditional parental website notification. Group 3 = Real-time parental website notification only. Group 4 = Control.</td>
<td>Single group, pre-post test design. Following examination of the data, analyses incorporated a between subjects approach. Group 1 = High-risk drivers (n = 7). Group 2 = Lower risk drivers (n = 18).</td>
<td>Single group, pre-post test design.</td>
<td>Between subjects design (RCT). Group 1 = ‘Lights only’ group receiving real-time visual feedback only. Group 2 = ‘Lights plus’ group receiving real-time visual feedback, online post-journey feedback and weekly emailed parental reports including access to video footage.</td>
</tr>
<tr>
<td><strong>Driving Outcomes</strong></td>
<td>Changes in extreme manoeuvres not significant over time. Group specific speeding and sudden braking/acceleration decreases, increased seatbelt usage reported.</td>
<td>Overall reduction of 58% in ‘safety-related’ events and 15% increase in seatbelt use.</td>
<td>Reduction of 50% in safety-related events with in-vehicle and parental feedback.</td>
<td>Significant reductions in unsafe driving events recorded for the ‘Lights Plus’ group only.</td>
</tr>
<tr>
<td><strong>Type of Monitor</strong></td>
<td>IVDR</td>
<td>DriveCam IVDR</td>
<td>Green Box IVDR</td>
<td>DriveCam IVDR</td>
</tr>
<tr>
<td><strong>Device Functionality</strong></td>
<td>Measured sudden braking and acceleration, non-use of seatbelts and vehicle speed in relation to posted limits. Provided real-time audio feedback and online</td>
<td>Recorded video of and measured events related to g-force violations including crashes, hard braking and acceleration, hard turning and cornering. Provided real-time visual</td>
<td>Measured ‘risky driving events’ including extreme braking and accelerating, sharp turning and sudden lane changing. Provided real-time feedback and post-journey (online)</td>
<td>Recorded video of and measured events related to g-force violations including crashes, hard braking and acceleration, hard turning and cornering. Provided real-time</td>
</tr>
</tbody>
</table>

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notifications (real-time for Group 1 and 3, delayed for Group 2) to a website for parents. feedback (blinking red LED when an unsafe event occurred). Also provided post-journey feedback online and via weekly parental reports including a CD of recorded events. feedback reports, including weekly emails sent to participants and parents.

<table>
<thead>
<tr>
<th>Location</th>
<th>USA</th>
<th>USA</th>
<th>UK</th>
<th>USA</th>
</tr>
</thead>
</table>

*Not reported
### Table 15

*Quality assessment of extracted efficacy studies.*

<table>
<thead>
<tr>
<th>Study</th>
<th>Design</th>
<th>Described method of recruitment</th>
<th>Randomised-worksites or individual?</th>
<th>Eligibility criteria</th>
<th>Groups similar at baseline?</th>
<th>Investigator kept blind</th>
<th>Attrition reported</th>
<th>Non-randomised comparison</th>
<th>Per cent completing trial</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Albert et al. (2011)</td>
<td>Non-RCT (RM)</td>
<td>✓</td>
<td>N/A</td>
<td>✓</td>
<td>N/A</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Bolderdijk et al. (2010)</td>
<td>RCT</td>
<td>✓</td>
<td>Individual</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>62</td>
</tr>
<tr>
<td>Carney et al. (2010)</td>
<td>Non-RCT (RM)</td>
<td>✓</td>
<td>N/A</td>
<td>✓</td>
<td>N/A</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>50</td>
</tr>
<tr>
<td>Creaser et al. (2009)</td>
<td>Non-RCT (RM)</td>
<td>✓</td>
<td>N/A</td>
<td>X</td>
<td>N/A</td>
<td>X</td>
<td>N/A</td>
<td>X</td>
<td>N/A</td>
</tr>
<tr>
<td>Farmer et al. (2010)</td>
<td>RCT</td>
<td>✓</td>
<td>Individual</td>
<td>✓</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>McGehee et al. (2007)</td>
<td>Non-RCT (RM)</td>
<td>✓</td>
<td>N/A</td>
<td>X</td>
<td>N/A</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>96</td>
</tr>
<tr>
<td>Musicant et al. (2010)</td>
<td>Non-RCT (RM)</td>
<td>X</td>
<td>N/A</td>
<td>X</td>
<td>N/A</td>
<td>X</td>
<td>✓</td>
<td>X</td>
<td>100</td>
</tr>
<tr>
<td>Simons-Morton et al. (2013)</td>
<td>RCT</td>
<td>✓</td>
<td>Individual</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>X</td>
<td>98</td>
</tr>
</tbody>
</table>

*Note.* RCT = randomised control trial, Non-RCT (RM) = single group, repeated measures design.
C1.5 Results

Eight studies were identified that examined young driver monitoring ‘efficacy’ (see extraction Table 13) and that met the specified inclusion/exclusion criteria. These studies primarily dealt with two aspects of driving relevant to SDSSs - extreme driving manoeuvres and speeding behaviour.

*Extreme manoeuvres*

‘Extreme driving manoeuvres’ refer to driving that involves combinations of speed (although not necessarily speeding violations), acceleration/deceleration, and repositioning on the road: turning at excessive speed, hard acceleration, or braking harshly, for example (e.g. Simons-Morton et al., 2013). In the context of driver monitoring, these are identified as driving events that exceed previously set acceptable vehicle gravitational-force (g-force levels), which then trigger an alert (e.g. Musicant & Lampel, 2010). Extreme manoeuvres are frequently implicated in young driver crashes involving novice drivers (Clarke, Ward, Bartle, & Truman, 2006).

Six studies examined the impact of an IVDR on extreme driving manoeuvres. Of these, two were RCTs. Simons-Morton et al. (see Table 13, Study h) conducted a RCT in the United States with 88 parent-teen dyads with newly licensed (< 30 days) drivers under the age of 18. Each dyad was randomly assigned to one of two experimental conditions. Group 1 (‘Lights Only’) received real-time in-vehicle feedback from a video-based monitoring device (DriveCam), with LED lights providing visual alerts. Participants in Group 2 (‘Lights Plus’) received both in-vehicle and post-journey personalised feedback. Feedback included video footage of unsafe driving events, which was also made available to parents. ‘Events’ were defined as elevated g-force exceeding 0.5g, weighted by distance travelled. The efficacy of the interventions was established by comparing an initial baseline period (recording, but no feedback) with a testing period (12 weeks), across the two groups. The authors reported no difference in events across groups during baseline testing, but a significant decrease in events in the Lights Plus group over time. There were no differences in the Lights Only group over time and the magnitude of the difference across the two groups was large (\(d = 1.67\)). The study points towards the potential value of combining external monitoring, post-journey synthesis of performance, and real-time alerts. The long-term impact of the monitoring intervention was not examined however, and there were no significant differences in crashes or near crashes across the two groups. In reality this is to be expected, given the relatively small sample sizes and the rarity of such events.
Farmer et al. (2010; see Table 13, Study e) conducted an IVDR RCT in Washington DC. Eighty-four recently licensed teen drivers (aged 16-17) provided usable data on incidences of sudden acceleration and braking as one of their outcome measures. Each participant was randomly assigned to one of four conditions. Group 1 received in-vehicle alerts and a notification was immediately logged on the website accessible to parents for any incidents violating the threshold. Group 2 also received in-vehicle alerts, but were given 20 seconds to correct their behaviour before a parental notification was sent (i.e. they received a ‘conditional’ alert). Group 3 did not receive in-vehicle alerts, but events were posted to the parental website immediately. Finally Group 4 (the control group) simply drove with a monitor installed in their vehicle. Participation involved a two-week baseline period, 20-week treatment phase and final two-week post-treatment stage. The impact of IVDR monitoring (Groups 1-3) on extreme driving manoeuvres was not statistically significant.

In addition to these RCTs, three single-group studies examined the influence of in-vehicle feedback and monitoring on extreme driving manoeuvres. Musicant and Lampel (2010; see Table 13, Study g) recruited 32 young drivers (17-24 years of age) in the UK to drive with their Green Box monitor during a six-month intervention. Following an initial information session and three-month baseline phase, drivers received in-vehicle alerts for instances of extreme braking/acceleration, sharp turning and sudden lane changing, and post-journey web reports and emails which parents could also access. Following this intervention, extreme driving manoeuvres reduced by approximately 59% from baseline (paired t = 4.3, p < .01). Twenty-eight of the 32 drivers were found to have reduced their initial event frequency score, with 25 of these reporting significant reductions. Monitoring had the largest impact for drivers who engaged in more extreme driving at baseline.

McGehee et al. (2007; see Table 13, Study f) recruited 26 newly licensed drivers from a rural area in Iowa to participate in their DriveCam intervention. The baseline measurement period lasted nine weeks, after which time the 36-week treatment phase began. In total, 25 participants provided data for final analyses. The young drivers received in-vehicle feedback via the DriveCam LED system, with a green light indicating safe driving, and a red light indicating that an unsafe manoeuvre (i.e. exceeding a threshold, such as an improper turn) had occurred and been recorded. A Compact Disk (CD) containing video clips of these unsafe events was sent to the parents of each participant every week, featuring simple interpretations of the data provided relative to their peer group, with suggestions as to how to improve the driving skills of the driver. Overall, the
full sample reduced their events rate by 58% (8.6 to 3.6 events per 1000 miles) by week nine, and by 76% (8.6 to 2.1 events per 1000 miles) by week 18, an effect that was maintained to the end of the study. When drivers were divided into high (n = 18, who at baseline, averaged 23.4 unsafe events per 1000 miles) or low (n = 7, 2.5 unsafe events per 1000 miles at baseline) risk groups, the greatest improvements were reported for those at higher-risk at baseline. Their events were found to reduce to 6.4 per 1000 by week 9, to 2.6 at week 18, to an average of 3.0 for the remainder of the intervention.

Carney et al. (2010; see Table 13, Study c; 2007) recruited 36, 16-year-old drivers from Minnesota to examine the effects of a DriveCam intervention in an urban environment. Participants had typically been driving unsupervised for less than five months, and 18 provided data for the final analyses. Extreme manoeuvres, or ‘coachable events’, took the form of hard acceleration and braking, and hard cornering or swerving. They collected data during a pre-testing baseline phase (i.e. no feedback over six weeks), an intervention phase (40 weeks with feedback) and post-intervention phase (no feedback over six weeks). DriveCam feedback was immediate (in-vehicle, via flashing LEDs) and delayed (summary reports to parents). The number of events reduced by 61 percent, from 21 events per 1000 miles during first baseline to an average of 8 per 1000 miles post-intervention ($\chi^2 = 11.42, p = .001$), which was maintained for the post-intervention period. Here, monitoring was also found to have the greatest impact on drivers with the highest levels of extreme manoeuvres during the initial pre-testing stage.

Last, one study utilised a pre-post test design examining the effects of an IVDR intervention, but did not involve parents in the monitoring process. G. Albert et al. (2011) conducted an eight-month study of 32 drivers in Israel, using an IVDR providing immediate in-vehicle feedback via flashing red or green LED lights and post-journey reports. This included a 2.5 month baseline phase, a 3.5 month treatment phase and two month post-treatment period. The average age of participants at the outset of the study was 20.5 years, and participants had typically been driving for three to four years. ‘Safety events’ were defined as involving dangerous braking, accelerating, turning, lane handling and speeding. The impact of monitoring on safety events at any stage in this study was not statistically significant. It is possible that this is due, in part, to their recruiting a sample with positive attitudes towards road safety, ‘a large fraction’ (p. 342) of whom were involved in military service during the study.
**Speeding**

Three studies that met the inclusion criteria reported findings specific to monitor use and speeding. As previously outlined, speeding marks one of the most common and most dangerous driving violations by those under the age of 25, serving to substantially increase both RTC risk and the severity of injuries sustained should a collision occur (Fleiter, Watson, Lennon, & Lewis, 2006).

Farmer et al. (2010; see above, and Table 13, Study e) conducted a study involving 84 newly licensed teen drivers which also examined speeding violations, where this incorporated driving at 10mph or greater above the posted speed limit. Speeding was analysed in terms of total miles driven while speeding, rather than event frequency counts. The only reduction recorded was for Group 2, which received in-vehicle alerts and had 20 seconds to change their unsafe behaviour before an online notification was sent to their parents (i.e. a conditional alert). Overall, drivers in this group reported speeding for 14% of their miles driven at the baseline period and 10% of their miles driven during the intervention. This was a statistically significant short-term impact. However, in the post-treatment phase, this increased to 12%. According to the authors, this ‘still was lower than would have been expected if the treatment had not been applied’ (p. 42). Interestingly, drivers in the immediate alert + web feedback (Group 1), web-feedback only (Group 3) and control groups (Group 4) reported increases in speeding over the course of the project, though insufficient statistical information is provided to interpret the significance of these increases.

Bolderdijk et al. (2011) conducted an eight month insurance incentivised ‘Pay-As-You-Drive’ monitoring study in the Netherlands with 141 young drivers assigned to either incentive-based (two groups) or control (one group) conditions. The two incentive-based groups received post-journey, summary feedback. The first ($n = 50$), received information on the initiative that was gain-framed, focusing on the insurance discount that could be earned (€50) though adhering to the speed limits. The second ($n = 50$) received information that was loss-framed, describing the discount that could be lost (up to €50) through violation of speed limits. The control group ($n = 41$) were told they would receive the insurance discount for participation alone. The dependent variable in the design was the weekly percentage distance travelled at 6% or more above posted legal limits. No effect of gain or loss framing was found and incentive-based groups were combined ($n = 100$) and compared to the performance of control group drivers. The percentage speeding of the intervention group decreased significantly after the incentive was introduced, from 18.6%
(baseline, 1-2 months) to 17.7% at intervention phase 1 (+3/4 months). This reported a partial $\eta^2$ value of .122, a small-medium effect. This reduction was maintained at 17.6% at intervention phase 2 (+5/6 months), but increased significantly to 20.5% post-treatment (+7/8 months). Conversely, the speeding behaviours of the control group increased significantly from baseline (17.9%) to the final measurement phase (19.7%).

Last, a smaller-scale field study was published by Creaser et al. (2009) to pilot their smartphone Teen Driver Support System (‘TDSS’) in Minnesota (see Table 1, Study d). This featured a SDSS which functioned in conjunction with additional in-vehicle hardware (including a GPS transmitter device). A total of 16, 18-19 year old participants were recruited to drive a 30-minute circuit (8.7 miles) without real-time feedback, and then complete the same circuit with alerts (for speeding, curve negotiations, stop sign violations and weather alerts) in place. A significant reduction in speeding from 30.9% of the course to 18.2% was reported. Due to insufficient data reported, no effect size statistic could be calculated. The limited sample and presence of a researcher also undermined the external validity of the study.

Behaviour Change Techniques

In all, BCTs from six clusters emerged from analysis of the eight studies (see Table 15). These were BCTs pertaining to the ‘2. Feedback and Monitoring’, ‘6. Comparison of Behaviour’, ‘7. Associations’, ‘10. Reward and Threat’, ‘12. Antecedents’, and ‘14. Scheduled Consequences’ clusters. The number of BCTs featured in each study varied, from just two coded BCTs in the G. Albert et al. study, to eight being coded in Bolderdijk et al. (2011). In many cases it is likely that a greater number of BCTs were utilised during the monitored period, however, these were described in insufficient detail to reliably code them (e.g. G. Albert et al., 2011). This is a common issue throughout the behaviour change literature (Michie et al., 2013).

First, three BCTs from cluster ‘2. Feedback and Monitoring’ were coded. The BCT ‘2.2 Feedback on behaviour’ was coded in all of the eight studies, referring to when the target behaviour is monitored and informative or evaluative feedback is provided (e.g. on form, frequency, duration or intensity). This was provided in every efficacy study examined here, via either real-time, in-vehicle feedback or post-journey evaluative reports. In the McGehee et al. (2007) study, for example, participants received real-time LED light feedback from a DriveCam device when their driving exceeded safety thresholds. The BCT ‘2.3 Self-monitoring of behaviour’ was coded in the Bolderdijk study alone. This BCT is
<table>
<thead>
<tr>
<th>Study</th>
<th>BCTs Used</th>
</tr>
</thead>
<tbody>
<tr>
<td>G. Albert et al. (2011)</td>
<td>2.2 Feedback on behaviour</td>
</tr>
<tr>
<td></td>
<td>12.5 Adding objects to the environment</td>
</tr>
<tr>
<td>Bolderdijk et al. (2011)</td>
<td>2.2 Feedback on behaviour</td>
</tr>
<tr>
<td></td>
<td>2.3 Self-monitoring of behaviour</td>
</tr>
<tr>
<td></td>
<td>2.7 Feedback on outcome(s) of behaviour</td>
</tr>
<tr>
<td></td>
<td>10.1 Material incentive (behaviour)</td>
</tr>
<tr>
<td></td>
<td>10.2 Material reward (behaviour)</td>
</tr>
<tr>
<td></td>
<td>12.5 Adding objects to the environment</td>
</tr>
<tr>
<td></td>
<td>14.1 Behaviour cost</td>
</tr>
<tr>
<td></td>
<td>14.3 Remove reward</td>
</tr>
<tr>
<td>Carney et al. (2010)</td>
<td>2.2 Feedback on behaviour</td>
</tr>
<tr>
<td></td>
<td>12.5 Adding objects to the environment</td>
</tr>
<tr>
<td>Creaser et al. (2009)</td>
<td>2.2 Feedback on behaviour</td>
</tr>
<tr>
<td></td>
<td>12.1 Restructuring the physical environment</td>
</tr>
<tr>
<td>Farmer et al. (2010)</td>
<td>2.2 Feedback on behaviour</td>
</tr>
<tr>
<td></td>
<td>7.5 Remove aversive stimulus</td>
</tr>
<tr>
<td></td>
<td>12.5 Adding objects to the environment</td>
</tr>
<tr>
<td></td>
<td>14.2 Punishment</td>
</tr>
<tr>
<td>McGehee et al. (2007)</td>
<td>2.2 Feedback on behaviour</td>
</tr>
<tr>
<td></td>
<td>6.2 Social comparison</td>
</tr>
<tr>
<td></td>
<td>12.5 Adding objects to the environment</td>
</tr>
<tr>
<td>Musicant &amp; Lampel (2010)</td>
<td>2.2 Feedback on behaviour</td>
</tr>
<tr>
<td></td>
<td>6.2 Social comparison</td>
</tr>
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<td></td>
<td>10.1 Material incentive (behaviour)</td>
</tr>
<tr>
<td></td>
<td>10.2 Material reward (behaviour)</td>
</tr>
<tr>
<td></td>
<td>12.5 Adding objects to the environment</td>
</tr>
<tr>
<td>Simons-Morton et al. (2013)</td>
<td>2.2 Feedback on behaviour</td>
</tr>
<tr>
<td></td>
<td>6.2 Social comparison</td>
</tr>
<tr>
<td></td>
<td>12.5 Adding objects to the environment</td>
</tr>
</tbody>
</table>
coded when a means for an individual to monitor and record their behaviour as part of a behaviour change strategy is provided and definitively described. In the Bolderdijk study, participants were encouraged to track their driving performance using a detailed, personalised webpage. The BCT ‘2.7 Feedback on outcome(s) of behaviour’ was also coded solely for the Bolderdijk et al. study, referring to when a target behaviour(s) is monitored, and feedback provided on the outcome of performance of the behaviour. In this case, young drivers received web-based feedback regarding the extent of their earned insurance discount (an outcome of their speeding behaviour to that date).

A single BCT was coded within the ‘6. Comparison of Behaviour’ cluster. This was ‘6.2 Social comparison’, which refers to drawing attention to others’ performance to allow comparison with the person’s own performance. This was present in the Musicant and Lampel (2010), McGehee et al. (2007) and Simons-Morton et al. (2013) studies. In the latter, for example, this was coded as the delayed feedback provided in the Lights Plus group included a report card detailing the teenage driver’s weekly events, and a graph of their weekly driving risk score relative to other teenage drivers. Likewise, a single BCT from the ‘7. Associations’ cluster was coded for the Farmer et al. (2010) study. This was ‘7.5 Remove aversive stimulus’, which describes a BCT wherein arrangements for the removal of an aversive stimulus to facilitate behaviour change are made or advised. It was coded in this case, as participants with real-time alerts were provided with aversive audible alerts immediately following each event, which would be terminated when the negative behaviour ceased.

Two BCTs were coded from the ‘10. Reward and threat’ cluster. These were ‘10.1 Material incentive (behaviour)’ and ‘10.2 Material reward (behaviour)’. The material incentive (behaviour) BCT is coded when the participant is informed that money, vouchers or other valued objects will be delivered if and only if there has been effort and/or progress in performing the behaviour. The ‘10.2 Material reward (behaviour)’ BCT involves arrangement for the delivery of money, vouchers or other valued objects if, and only if, there has been effort and/or progress in performing the behaviour. These were both coded for the Bolderdijk et al. (2011) and Musicant and Lampel (2010) studies. Taking the Musicant and Lampel study, for example, the 10.1 BCT was coded as their participants could accumulate points by driving safely to win different prizes. The 10.2 BCT was coded in the Bolderdijk et al. study, as this detailed how participants were informed of their potential to earn a specified insurance discount, provided safe driving behaviour was documented throughout the monitoring period.
Two BCTs were coded from the ‘12. Antecedents’ cluster. The BCT ‘12.1 Restructuring the physical environment’ was documented in the Creaser et al. (2009) study. This refers to the implementation of a change to the physical environment (in this case, the vehicle) to facilitate the wanted behaviour(s), and create barriers to the unwanted one(s). In this case, this referred to the provision of a SDSS to provide feedback on young driver behaviours. For all other studies, ’12.5 Adding objects to the environment’ was coded, on the occasion that the study definitively described the addition of an object/s (i.e. the IVDRs used) to the environment to facilitate performance of the target behaviour.

Last, three BCTs were coded from the ‘14. Scheduled Consequences’ cluster. These were ‘14.1 Behaviour cost’, ‘14.2 Punishment’ and ’14.3 Remove reward’. A ‘Behaviour cost’ (14.1) is coded when the withdrawal of something valued is arranged if the unwanted behaviour is performed. A ‘Punishment’ (14.2) then, is coded when aversive consequences are arranged if an unwanted behaviour is performed. Last, the removal of a reward (14.3 Remove reward) is coded when the discontinuation of a reward is arranged upon performance of an unwanted behaviour. The 14.1 and 14.3 BCTs were coded for the Bolderdijk et al. (2011) study, as the loss framed condition in this field test involved the potential removal of a €50 discount each month if speeding violations continued during the monitored period. The ‘Punishment’ BCT was coded for the Farmer et al. (2010) study, as participants with in-vehicle alerts received ‘beeps’ with increasing pitch and frequency if they exceeded (and continued to exceed) the speed limit.

With regards to the reviewed studies relating to young driver extreme manoeuvres, and the four that reported significant reductions (i.e. Carney et al., 2010; McGeehe et al., 2007; Musicant & Lampel, 2010; Simons-Morton et al., 2013), the ‘Feedback on behaviour’ (2.2), and ‘Adding objects to the environment’ (12.5) BCTs were recorded for all four studies. The ‘Social comparison’ (6.2) BCT was recorded for three out of the four, and ‘Material incentive (behaviour)’ (10.1) and ‘Material reward (behaviour)’ (10.2) BCTs for one of these. Of the three young driver studies that examined speeding as an outcome (i.e. Bolderdijk et al., 2011; Creaser et al., 2009; Farmer et al., 2010) all reported similar, small-scale improvements. All of these were found to feature the ‘Feedback on behaviour’ (2.2), and ‘Adding objects to the environment’ (12.5) BCTs. The Farmer et al. (2010) study also featured the ‘Remove aversive stimulus’ (7.5) and ‘Punishment’ (14.2) BCTs, with the Bolderdijk et al. study also including ‘Self-monitoring of behaviour’ (2.3), ‘Feedback on outcome(s) of behaviour’ (2.7), ‘Material incentive (behaviour)’ (10.1), and ‘Material reward (behaviour)’ (10.2). In all, the most common BCTs appearing across the eight
reviewed studies were ‘Feedback on behaviour’ (2.2) (eight out of eight studies), ‘Adding objects to the environment’ (12.5) (seven out of eight studies), and ‘Social comparison’ (6.2) (three out of the eight studies).

C1.6 Discussion

The objective of this systematic review was to examine the broader IVDR efficacy literature, and consider how synthesised findings could help inform an understanding of the potential value of SDSSs in reducing young driver risk-taking. The review also sought to garner evidence with regards to the underlying mechanisms of change targeted in the monitoring programmes, anticipating that they would have harnessed known BCTs. Efficacy

Overall, the studies reviewed here have reported inconsistent findings for the efficacy of in-vehicle monitoring on young driver behaviour. First, in relation to extreme manoeuvres, four of the six studies examined reported medium to large reductions in the frequency of this form of risky driving (Carney et al., 2010; McGehee et al., 2007; Musicant & Lampel, 2010; Simons-Morton et al., 2013). However, both the G. Albert et al. and Farmer et al. studies reported non-significant effects. Farmer and colleagues suggest that this may be due to the feedback alerts sounding ‘only briefly after each sudden braking/acceleration event and were not particularly annoying’ and that as a result ‘alerts themselves probably had little effect’ (p. 43). G. Albert and colleagues attribute their non-significant findings to a relatively small sample size ($n = 32$) and that the sample were predominantly in military service. They appear to be suggesting that these individuals are coming from a low baseline rate of risky driving, and that monitoring would be unlikely to have a significant effect on their rule violation (i.e. a ‘floor effect’). This resonates with an important finding from this systematic review, that when attempting to reduce extreme manoeuvres, monitoring has the greatest impact on those drivers who engaged in the most risky driving pre-intervention. This is a promising finding, as it demonstrates the potential of this technology to improve the driving and practices of those who are most at risk of a RTC.

In looking at the studies that directly examined the impact of monitor use on speeding, these would suggest that monitoring may have a positive effect upon young driver speed. Given that speeding has been recognised as the single most risky behaviour that a young, inexperienced driver can engage in (e.g. Gheorghiu et al., 2015), and that the findings from the Creaser et al. (2009) study mirrored the overall trends revealed by
young driver IVDR research, this attests to the potential positive effects of widespread SDSS monitoring. The following points should be noted however.

First, the magnitude of the effects appeared to vary across the studies. The reductions reported by Farmer et al., for example, appeared to be small, with a decrease in miles speeding from 14% to 10% overall. Similarly, in Bolderdijk et al.’s study the decrease was from 18.6% at baseline to 17.7% during the intervention. Also, while more substantial reductions were reported by Creaser et al., these were based on a comparison of speeding while the subject drove a 8.7 mile circuit twice, once without the monitor and once with it in-use, all while in the presence of a researcher. As such, it is difficult to draw any definitive inferences with regards to efficacy from this small-scale pilot. It is also possible that individual difference variables, and the extent to which the monitoring device and process is deemed acceptable by the young driver influences the extent to which they engage with it, impacting on the behaviour change process.

In addition, effects reported in some of the studies did not endure after feedback ended, with both the Farmer et al. and Bolderdijk et al. studies reporting increases in speed in the final, unmonitored phases of their research. Creaser and colleagues did not conduct a follow-up monitoring (no feedback) phase in their intervention. As such, it is unclear if short-term monitoring and feedback has any medium-to-long term impact on driver speed. This has implications for the utility of SDSS for driver training and usage, and it may be the case that the system is only effective when actively in use.

Overall, it would appear that monitoring and feedback can have a positive impact on both speeding and extreme manoeuvres, and that this is likely to have the greatest value for those young drivers who engage in higher levels of risky driving. It also seems that short-term monitoring and feedback interventions do not have a long-term impact on risk mitigation however, and are only effective when in use. The use of larger (i.e. greater than those offered in the Bolderdijk et al. study) insurance-based incentives to be earned over time may prove influential in this regard. In addition, the role of external monitors (i.e. parents, insurers, or indeed, researchers) may need to be examined. In the case of the majority of studies reviewed here, for example, parents were actively involved in the monitoring process. In Ireland, SDSSs are typically provided to a young driver in the knowledge that they will be monitored by their insurer, and feedback provided to them personally, rather than to a parent. Of note, much of the monitoring research conducted that has examined a level of parental involvement (either in receiving real-time alerts about their child’s driving, or post-journey feedback reports etc.) has been in countries
with younger licensing ages (e.g. the United States). Young drivers aged 18-24 however, may no longer live at home, and may pay for their own vehicle, insurance etc., such that using parents as external monitors is not practical. This suggests that a focus on evaluating the role of insurers, and financial incentives in evoking driving-related behaviour change may be optimal going forward. The findings of the Bolderdijk et al. study are most relevant in this regard, and attest that this is a potentially effective means of incentivising driving improvements. Given the inconsistent nature of the review findings, more stringent monitoring research needs to be carried out to examine this more closely, and examine if the SDSS monitoring and incentivisation process will be as effective as IVDR based studies.

**Behaviour Change Techniques and theory**

None of the eight studies reviewed explicitly set out the BCTs that underpinned their driver monitoring interventions. However, there was sufficient information present in the papers to identify the dominant BCTs harnessed. Two theories of behaviour change emerged from the studies reviewed (as identified through the coded BCT content). These were: a) Self-Regulation (SR) and; b) Operant Conditioning (OC).

**Self-regulation theory**

The first set of BCTs from the ‘Feedback and Monitoring’ and ‘Comparison of Behaviour’ clusters appeared to promote SR. Self-regulation, often referred to as ‘self-control’, relates to an individual’s capability to actively override impulses and inhibit responses such as thoughts, desires, emotions and behaviours (Baumeister, DeWall, Ciarocco, & Twenge, 2005). The specific techniques from the taxonomy directly related to SR were ‘2.1 Monitoring of behaviour by others without feedback’, ‘2.2 Feedback on behaviour’, ‘2.3 Self-monitoring of behaviour’, ‘2.7 Feedback on outcomes of behaviour(s)’ and ‘6.2 Social comparison’.

From these BCTs, it can be proposed that the use of an IVDR or SDSS can have positive effects on driving-related, risk-taking as these devices/interventions operate within the remit of SR models for behaviour change (e.g. Miller & Brown, 1991). Extended from its original form (a tripartite model consisting of self-monitoring, self-evaluation and self-reinforcement processes; Bandura, 1986; Miller, Toscova, Miller, & Sanchez, 2000), the Miller and Brown model of SR theory posits that seven phases are involved in successfully evoking behaviour change. These phases are typically more effective for those high in trait SR, however, research has found that the more often an individual self-regulates their behaviour (e.g. practicing under laboratory conditions), the better they become at doing so
These stages involve information input, where information on progress towards a goal is received from various sources (e.g. from objective SDSS feedback); self-evaluation, where current behaviour is compared with ideal performance; instigation to change (triggered by any behavioural discrepancies identified); search for ways to reduce the discrepancy; planning for change (e.g. from post-journey feedback suggestions); implementation of the behaviour change, and a ‘loop’ back to the initial stages, to evaluate progress towards the goal. The use of a monitor that provides objective, real-time and post-journey feedback on performance (including longer-term recommendations and guidelines to further improve behaviour), and the facilitation of social comparison, can potentially have a positive effect on driving behaviour by promoting SR, particularly when such behaviours are further incentivised by rewards, and discouraged by penalties. The potential efficacy of SDSSs also maps on to more recent, complimentary conceptualisations of SR (Baumeister & Vohs, 2007), wherein the SR process is understood to consist of standards (that is, standards that behaviour is compared against), monitoring (as in order to regulate behaviour, one must keep track of it), willpower (a self-regulatory resource, akin to energy or strength), and motivation (i.e. motivation to achieve the desired goal, meet the standard and regulate the self). Additional BCTs coded within the ‘Reward and Threat’ cluster throughout the efficacy studies can potentially be considered as relevant to SR theory here too, in that achieving an insurance discount, or avoiding a financial penalty may be the goal that behaviour is initially examined in relation to, thereby initiating the SR process.

In all, SR has been linked to a vast number of positive behavioural outcomes, including improved mental health and coping skills, physical health, maintaining healthy social relationships, adherence to medications, and low levels of criminal offending (Baumeister & Vonasch, 2015; Buhrau & Sujan, 2015). Interventions harnessing SR mechanisms have been found to reduce a range of unhealthy risk behaviours such as binge drinking and alcohol consumption, drug-taking, to decreasing sedentary lifestyles (Fleig et al., 2013; Neal & Carey, 2004). It is likely that the use of an in-vehicle monitoring device will have similarly positive effects on risk-taking because they operate within the remit of SR models for behaviour change.

**Operant conditioning**

Operant or instrumental conditioning refers to learning that occurs when the consequences that are conditional on an action update the likelihood that it will be performed again (Gazzaniga & Heatherton, 2006). When consequences increase the
probability that the behaviour will occur, this is termed reinforcement, and when consequences reduce the probability of behaviour, this refers to punishment. Although initially studied predominantly in relation to animal behaviour, extensive research has since attested to the value of reinforcement and punishment in shaping human action, such as reducing self-injurious behaviour, and enhancing inhibitory control (e.g. see Gazzaniga & Heatherton, 2006; Kahng, Iwata, & Lewin, 2002; Ma, van Duijvenvoorde, & Scheres, 2016; Schindler & Goldberg, 2013). Behaviour change techniques from the ‘7. Associations’, ‘10. Reward and Threat’, and ‘14. Scheduled Consequences’ clusters can be interpreted as relating to operant conditioning. The specific techniques coded from the studies reviewed here included providing a ‘10.1 Material incentive’, ‘10.2 Material reward’, ’14.1 Behaviour cost’, ’14.2 Punishment’, and the potential to ‘14.3 Remove reward’. Although only three of the research studies featured these specific BCTs, these features have strong ecological validity, as SDSSs and IVDRs are commonly offered with financial (insurance discount-related) incentives.

Reinforcement and punishment can be established by presenting additional consequences (i.e. positive reinforcement and positive punishment), or by removing expected consequences (i.e. negative reinforcement and negative punishment). In order to relate these terms to specific interventions, consequences can be labelled in terms of their effects. Consequences that are added or removed to increase behaviour are called reinforcers and the consequences that are adjusted to reduce behaviour are called punishers. Positive reinforcers are typically pleasurable, valued rewards that, when administered conditional on a particular behaviour, increase the probability of that behaviour being repeated. In a SDSS use context, the receipt of long-term feedback reports that acknowledge and praise improvements, or parental praise if they are involved in the monitoring process, can similarly be regarded as positive reinforcement of safe driving behaviours. Similarly, the provision of insurance discounts for safe driving behaviour may be construed as positive reinforcement, if drivers want to exchange the money they save for pleasant outcomes (e.g. goods or services). If participants simply do not like spending money, or they need money to reduce debts, then insurance discounts operate as negative reinforcers. The loss of an insurance discount should safe driving decrease over the specified time period, can also be regarded as a negative reinforcement of safe driving.

In addition to reinforcement effects, SDSSs may reduce inappropriate driving behaviours, such as speeding, through punishment. The provision of an aversive audio tone (such as a loud beep), and/or visual image (e.g. a flashing red light) is an unpleasant
stimulus that may decrease the likelihood of the undesirable driver behaviour recurring, i.e. a positive punishment. Insurance discounting tied to SDSS monitoring may also punish inappropriate driving behaviours. If the driver identifies that speeding was the reason that they lost a discount, then speeding is negatively punished if the driver wished to exchange the saved money, or positively punished if monetary losses are deemed aversive in and of themselves. The aversive effects of tones provided by the SDSS will be enhanced if there is a relationship between these responses and eventual negative financial outcomes (secondary positive punishment).

The importance of the immediacy of punishments and reinforcers in influencing behaviour has been noted (Miltenberger, 2012), and does vary in this context. Positive punishers of unsafe behaviours, such as in-vehicle alerts may be provided in real-time, for example, but these depend on the salience of the delayed loss of an insurance discount that may occur months later. In addition, there is on-going debate as to the value of using aversive techniques such as negative reinforcement and punishment when attempting to change behaviour, and if resulting changes endure in the long-term (Miltenberger, 2012; Staddon & Cerutti, 2003). In particular, attempting to reduce a current behaviour without teaching an appropriate replacement behaviour that will provide access to positive reinforcement is to be avoided. When considering the behavioural effects of SDSS-provided consequences, it is clear that these effects will likely vary depending on the valence of, for example, monetary savings and rewards for the individual driver. By incorporating driver data and preferences, SDSS research may address these issues in future, in light of the previously expressed efficacy concerns.

*Theoretical implications for SDSS use*

In considering potential SDSS efficacy, the studies discussed in the systematic review have attested to the positive impact that IVDRs may have upon risky driving behaviours through the use of monitoring, provision of feedback and incentivisation of safe driving. A number of primary factors contributing to young driver crash risk, such as engagement in extreme manoeuvres and speeding have been found to improve significantly with monitor usage. While the literature has indicated that the use of in-vehicle monitoring systems can promote positive behaviour change, as of yet, very little has been posited in relation to the exact psychological mechanisms, or theoretical foundations, underlying this effect. Based on the findings of the efficacy systematic review, and drawing from the greater behavioural change literature, the following framework is hypothesised from which the
extent of the efficacy of an in-vehicle monitoring system such as an SDSS can begin to be understood.

The degree to which in-vehicle monitoring technology (i.e. SDSSs and/or IVDRs) influences risk-taking, may be construed as depending on a combination of both ‘top-down’ and ‘bottom-up’ factors. In this context, top-down factors relate to the IVDR or SDSS technology itself, how their use can provide monitoring, real-time and post-journey feedback, and financial incentives to motivate behaviour. The bottom-up factors refer to the psychological characteristics or individual differences of the user, which moderate the effects of the above. These relate to traits (such as trait SR or delay discounting and overall acceptance of monitors.

**Monitoring**

The monitoring process in the context of SDSS or IVDR use typically refers to monitoring by external parties, wherein an individual’s driving performance is recorded by technology for the scrutiny of another, either in real-time, or post-journey. Of note, certain SDSSs can be offered on app stores, online etc. for personal use, wherein driving records are provided solely for the driver. In-vehicle monitoring is itself a relatively recent addition to the broader monitoring literature. Monitoring technology research thus far has primarily concerned the Electronic Performance Monitoring (‘EPM’, e.g. Lund, 1992; Zweig & Webster, 2003) of employees in the workplace, wherein performance indicators (such as engagement with online clients, management of company email etc.) are constantly recorded and sent to a supervisor or manager. Conceptually similar work on the ‘Hawthorne effect’, has also documented that being monitored alone has been shown to have a positive impact on performance (e.g. De Amici, Klersy, Ramajoli, Brustia, & Politi, 2000; Leonard, 2008; Mangione-Smith, Elliott, McDonald, & McGlynn, 2002), with individuals typically responding to knowledge of observation in a socially desirable way (McCambridge, Witton, & Elbourne, 2014). This resonates with the driver monitoring literature, as it has been noted that control group participants and initial baseline measures for groups frequently display lower levels of risk-taking than typically reported in driving studies, and this has been attributed to the presence of an IVDR in their vehicle (e.g. Farmer et al., 2010). The implementation of the monitoring process is not always effective however (e.g. G. Albert, Musicant, Lotan, Toledo, & Grimberg, 2011), and a number of individual difference variables may influence this.

In line with SR theory, the implementation of external monitoring may prompt a degree of behavioural SR in itself, as the individual seeks to behave favourably, in line with
expectations of the monitor (either the self and/or another party). As such, an individual’s trait SR, or the extent to which they can typically self-regulate, may be of importance in the context of SDSS use (Baumeister, Gailliot, DeWall, & Oaten, 2006). The knowledge that one is being externally monitored can evoke self-monitoring processes, wherein an individual monitors their own performance, to compare it to personal standards and criteria, and adjust their driving in the case of any perceived discrepancies. Although any improvements produced may not be substantial (in the absence of feedback to denote the true extent of the discrepancies, for example), these may still occur, in line with the aforementioned EPM and broader monitoring research findings. An individual’s capacity to do so (i.e. trait SR) will likely influence the extent to which this occurs.

In addition to this, when monitoring alone is reported to positively influence behaviours, this may be due to individual differences in adopting either ‘approach’ or ‘avoidance’ type responses to the awareness of being monitored (Biesinger & Crippen, 2010). How an individual construes their situation affects the behavioural processes that operate. In the monitoring context, approach responses are observed when an individual behaves in the knowledge that they are being observed with the goal of ‘doing well’, of succeeding and showing the external monitors how capable they are. Such individuals are operating under a positive reinforcement contingency. Conversely, avoidance responses are observed when a person improves their behaviour to avoid perceived displeasure over a potentially poor performance. It is possible that individuals are predisposed as to whether they react with approach or avoidance responses specifically when being monitored (e.g. see Pickering & Corr, 2008).

In the context of SDSS use, an individual’s fear of negative evaluation (‘FNE’; Duke, Krishnan, Faith, & Storch, 2006; Rodebaugh, Holaway, & Heimberg, 2004) may play a role here. This denotes an apprehension about other’s appraisals, and distress over potential negative judgement. In order to avoid failure (and the potential to be evaluated negatively), such individuals may be strongly motivated to change any risky driving behaviours when aware performance is being monitored. Interestingly, FNE is only adaptive to a certain extent. Studies have found that for individuals with high FNE in high-pressure situations, the desire to avoid negative evaluation can actually result in worse performance overall (Mesagno, Harvey, & Janelle, 2012). This is in keeping with a number of EPM studies wherein employees have reported significantly poorer outcomes following the implementation of monitoring (often coupled with noted increases in employee stress and workplace dissatisfaction; Schleifer & Shell, 1992), and SR theory, which states that the
capacity to self-regulate may become depleted following increasing emotional and behavioural inhibition (Baumeister & Vohs, 2007).

Last, as discussed in Section B, it is likely that an individual’s acceptance of the idea and process of monitoring may also play a role in whether monitoring alone has an impact upon behaviour. Individuals opposed to the concept of monitoring, for example, are unlikely to be motivated by the knowledge that they are being observed to change their behaviour.

Feedback

Feedback refers to information received by an individual relating to his/her past behaviour (Arnett, 1969; Hermsen, Frost, Renes, & Kerkhof, 2016). Performance feedback has been a topic of psychological research for decades, particularly in relation to organisational psychology, education, and learning (Alder, 2007; Hattie & Timperley, 2007). In recent years however, the need for systematic driver feedback has been highlighted (e.g. Dogan et al., 2012) in order to improve driver skills, and reduce risk-taking. As stated throughout Chapter 1, once licensed, young drivers rarely receive further instruction or feedback on their driving due to the cessation of supervision, and the forgiving nature of the traffic environment. This is problematic, given their lack of experience with more varied on-road situations, and knowledge of the impacts of their mistakes (White et al., 2011).

The theory of SR, (and, indeed, a number of competing theories of behaviour change, such as control theory, see B. Gardner, Whittington, McAteer, Eccles, & Michie, 2010b), recognises the need for accurate performance feedback in order to improve behaviour. The provision of in-vehicle alerts and post-journey summary reports is directly in line with SR theory. First, real-time driver feedback provides the performance information for self-evaluation of current behaviour in relation to attaining safer driving goals (or related insurance discount goals), prompting awareness of any discrepancies between target and actual behaviour. It can also facilitate evaluation of how well any newly adopted strategies are working towards achieving the goal. In-keeping with this, post-journey feedback typically includes indications of overall or mean performance (often with normative comparisons provided), descriptions and categorisations of errors made, and even the potential to re-visit any mistakes made via video footage if collected (e.g. Farmer et al., 2010; Simons-Morton et al., 2013). Post-journey reports also frequently feature suggestive strategies for young drivers to adopt to improve their behaviour, enhancing the ‘planning for change’ phase of SR.

In addition, it is worth noting that this kind of objective self-regulatory feedback may prove most effective in mitigating risk for drivers with a high optimism bias. It dispels any
erroneous perceptions of driving performance, by indicating the potentially large discrepancies between actual and ideal abilities, prompting regulation of behaviour towards driving-related goals. In keeping with this proposition, the research literature in relation to educational and learning psychology has reported that when students expect to do well, and do not, they ultimately improve and learn more than others, because of the extent to which they engage with the ‘surprising’ feedback they have received (e.g. Hattie & Timperley, 2007). This is also reflected in monitoring studies, which have found that higher risk drivers often show the greatest improvement following a monitoring intervention (e.g. McGehee et al., 2007).

Operant conditioning may also contribute to explanations of feedback effects. The receipt of feedback reports that acknowledge and praise improvements or parental praise if they are involved in the monitoring process, can be regarded as positive reinforcement of safe driving behaviours. As one might expect, there will be differences in how parental praise functions for the driver depending on their current relationship with their parents. As detailed previously, there are also positive punishments associated with real-time monitoring feedback that can influence behaviour change.

Financial incentives

Insurance companies are increasingly offering IVDRs or SDSSs to young driver customers to drive with in exchange for discounted insurance rates, with the potential to further reduce their premium upon provision of a safe driving record following a specified period of monitoring. The Irish insurance company ‘Axa’, for example (Axa, 2016), offer their young driver customers (aged 17-24) an initial discount of up to 20% for downloading and driving with their DriveSave SDSS, with the potential to qualify for a further 10% reduction over the course of the next year, provided they drive safely. Likewise, ‘No Nonsense Insurance’, a Dublin-based insurer, have made their ‘Top Driver’ app available free of charge, and customers can avail of a discount of up to 30% from their current premium, following an evaluation of their score once they have driven 800km (No Nonsense Insurance, 2016). Young drivers have consistently voiced that the potential to earn insurance discounts is a highly influential factor when it comes to considering driving with a monitoring device (e.g. Lerner et al., 2010; K. L. Young et al., 2003b), and as such, it is likely that any widespread drive towards adopting in-vehicle monitoring will feature some form of gain-framed, monetary incentive. Thus, this must be accounted for in any framework considering SDSS efficacy.
The literature regarding the financial incentivisation of behaviour change has reported mixed results in the past, with the proposition of monetary rewards showing varying effects on effort and consequent performance relative to the incentivised task or behaviour (Bains, Pickett, & Hoey, 1998; Bonner & Sprinkle, 2002; Mantzari et al., 2015; A. Scott et al., 2011). More recent, stringent systematic reviews and meta-analyses however suggest that financial gains can both significantly increase the uptake of healthy, lower-risk behaviours (e.g. vaccination attendance or screening, increased physical activity), and decrease engagement in high-risk, dangerous actions (e.g. smoking cessation), more than usual care or no intervention (e.g. Kane, Johnson, Town, & Butler, 2004; Purnell, Gernes, Stein, Sherraden, & Knoblock-Hahn, 2014). The few incentivised broader driver monitoring studies carried out, have shown equally promising effects, with reported significant reductions in risky driving (e.g. see Bolderdijk et al., 2011; Mazeureck & Hattem, 2006; Merrikhpour, Donmez, & Battista, 2014).

The importance of goals in relation to behaviour change has long been acknowledged, and numerous theories have attested to the fundamental role of goal setting for behavioural change (Bonner & Sprinkle, 2002; Hattie & Timperley, 2007; Riedel, Nebeker, & Cooper, 1988). Goals in terms of SR theory, for example, have been described as central to the self-regulatory process (Hoyle & Davisson, 2011). As stated, monetary goals, or financial incentives have been revealed as notably good motivators of behavioural regulation. Money is desirable in that it is a tangible reward, instrumental in obtaining things that people desire (such as material goods), has symbolic value due to its perceived relationship to prestige and status, and can clearly contribute to a young driver’s economic well-being (Bonner & Sprinkle, 2002). Locke, Shaw, Saari and Latham (1981) proposed that overall, financial incentives can cause individuals to set goals when they typically would not, to take on and set more challenging goals than usual, and display a higher level of goal commitment. The power of financial incentives in changing behaviour may thus result from the setting of higher ideal standards to compare against actual behaviour during the self-evaluation phase of SR, resulting in greater discrepancies and leading to increased iterations of the SR process (seen as goal commitment) once more. In terms of OC theory, the provision of insurance discounts for safe driving behaviour can be classed as positive reinforcement. The loss of an insurance discount should a young driver drive unsafely over the specified time period, for example, can also be regarded as a negative punishment, wherein the undesirable behaviour is reduced due to the removal of the pleasurable discount stimulus.
Of note, individual differences may still influence the efficacy of financial incentives in changing behaviour however, and must be acknowledged. One key variable may do so in particular: an individual’s trait tendency to discount delayed rewards. As described in Study 2, trait delay discounting refers to an individual’s preference for immediate rewards, versus those to be obtained at a later stage, even if the immediate reward is of lesser value (e.g. Odum, 2011). Delay discounting can thus be characterised as how a reward loses its value as the delay to its receipt increases, and in terms of personal risk-taking and health behaviours, can provide an explanation as to why an individual may choose a smaller, more immediate reinforcer (e.g. smoking a cigarette, using a tanning bed, driving at high speeds etc.) over a relatively larger, but delayed one (such as improved health, greater financial stability; Secades-Villa, Weidberg, Garcia-Rodriguez, Fernandez-Hermida, & Yoon, 2014).

Trait delay discounting is important in this context, as the vast majority of the potential rewards considered to be associated with SDSS use, are delayed. Although a small, initial discount on insurance may be provided upon agreement to drive with a monitor, providers typically offer an additional incentive to drive safely, with the promise of an even cheaper premium after, for example, six months. Additional gains, such as the improvement of driving skills from using a feedback device, or a decrease in penalty points, speeding tickets etc. received will similarly not be immediate. Thus, for individuals with high trait delay discounting who prefer smaller, immediately reinforcing rewards (such as, for example, the ‘thrill’ of driving at 130 km/h) to the prospect of delayed future insurance discounts, financial incentivisation may not be seen as a sufficiently valuable goal for changing behaviour. Such factors must be taken into account when seeking to examine SDSS efficacy.

**Limitations**

In all, the use of a SDSS represents a combination of monitoring, real-time and post-journey feedback, and financial incentivisation, processes, which may facilitate the phases of SR, while providing reinforcement for safe driving behaviours, and ‘punishing’ risky ones, harnessing OC. The findings of the systematic review suggest that SDSS monitoring can work to reduce risk-taking, but the findings are inconsistent and need to be examined from a SDSS-specific perspective. The following points in relation to the review must also be noted. First, relatively few young driver monitoring studies have been published to date, and as such, the extent to which studies could be excluded based on quality assessment criteria was limited. That is, few stringent inclusion/exclusion criteria could be applied without losing a large portion of the material available for review. The majority of studies
included did not feature a control group, for example, which would have ideally been an inclusion requirement. Accordingly, due to the inconsistent quality of the studies included, and number of diverse outcomes measured, an additional meta-analysis could not be conducted.

It must also be noted that, of the studies reviewed here, the majority featured limited participant samples. The use of convenience samples means that such participants may not represent the young driver group at large (e.g. unequal gender break-downs, or select age ranges), and more specifically, may not incorporate those who are prone to higher levels of socially undesirable, driving-related risk-taking. This is an important consideration when examining the conclusions drawn from the current systematic review. There is some evidence of risk-taking within the studies reviewed however (e.g. McGehee et al., 2007), which suggests that the samples used throughout the studies selected here may be more representative than anticipated. Still, more representative samples must be utilised in undertaking the future research recommendations outlined in the current paper. It must also be acknowledged that the novel features and limitations of SDSSs may evoke unprecedented behavioural effects, such that the absence of any definitive SDSS-specific research in this review means claims regarding SDSS efficacy cannot be made with certainty.

C1.7 Contribution
This study is the first systematic review of the young driver monitoring efficacy literature conducted to date. It has highlighted the high-risk driving behaviours that SDSS implementation may be able to improve once adopted, the mechanisms of change influencing this, and proposed the key theoretical processes likely underlying these effects. The limitations of the existing young driver IVDR studies reviewed during this process have also been acknowledged. This body of evidence can still now be used however to inform the design of higher-quality, SDSS-specific efficacy studies, and provide a thorough evaluation of their use in the context of young driver populations, as is the aim of the current programme of research.

C1.8 Conclusions
The findings of the systematic review suggest that in-vehicle monitoring and feedback provision may play a valuable role in improving young driver road safety, and that the
further development and investigation of SDSSs is merited. The BCTs coded in the reviewed studies indicate that SR and OC are likely the predominant underlying theoretical processes influencing the efficacy of these.

Research that specifically and extensively investigates the efficacy of SDSSs is necessary at this stage however. As has been previously highlighted, SDSSs are similar to IVDRs in many ways, but they do retain unique features and functionality that may influence young driver usage, and behaviour change, in ways not yet anticipated. SDSSs typically involve an insurer as an external monitor, and not parents as has typically been the case with IVDRs, for example. In addition, the low quality of the existing in-vehicle monitoring efficacy studies reviewed here point to the necessity for more controlled, empirical assessments of this research topic in future. Thus, there is a clear need for SDSS-specific, empirical efficacy research, that builds from the findings of this systematic review, and the greater driving monitoring and behaviour change literature. This is the focus of the remainder of this section.
Chapter 6 - Section C2: Evaluating the Driving Simulator Obtained to Complete SDSS Efficacy Research.

C2.1 Introduction

To date, there has been little research on SDSS efficacy conducted under controlled laboratory conditions. Addressing this gap in the literature is a core aim of the current programme of research and in order to do so, it was necessary to develop a sensitive, robust and ecologically valid research paradigm. Simulator research was also ethically necessary, as it would be unsafe to conduct FOTs at this stage, given how little is currently known regarding young driver SDSS usage (e.g. whether they are distracting). The current chapter details the characteristics of the driving simulator employed for the SDSS efficacy studies proposed within the thesis (Studies 5-7), and two studies that established features of the experimental protocol. First, the period of driving necessary for young driver participants to adapt to using the simulator equipment (Section C.2.1, Study 4a) was established. Then, relationships between behaviour in the driving simulator and self-reported driving were examined to investigate whether such behaviour provides valid measures of real-world young driving (Section C.2.2, Study 4b). Conclusions drawn from these findings are provided in Section C2.3. As the studies are not central to the overall research questions posed in the thesis, they are described and reported in summary form here.

C2.2 Abstract Study 4a

Background: In order for the behaviour recorded in a driving simulator to reflect actual driving abilities and skills, participants must first complete a practice trial to adapt and become ‘used’ to driving with the novel equipment. Varying adaptation periods (e.g. completing a 5km track, or a 5-minute drive) lacking specific rationales have been implemented throughout the driving research literature however, such that context-specific, evidence-based adaptation periods are necessary to ensure adaptation has occurred.

Aims: This study aimed to systematically identify the specific period of adaptation required by young drivers to adjust to using the novel driving simulator equipment at NUI Galway.

Methodology: An initial sample of ten young drivers were recruited to drive a 26.67km track, which consisted of 3 laps of the core experimental track to be used in subsequent SDSS empirical studies (Studies 5-7). Following this, lateral position related scores were examined graphically to indicate the point of adaptation (i.e. significantly improved performance). This
was revealed to be at the point of completion of the first lap. Data from the adaptation drives of a further 20 young drivers completing the subsequent SDSS empirical studies (Studies 5-7) were then extracted, and added to the dataset of the initial ten participants, to facilitate conducting inferential statistics, and confirm the selected adaptation period.

**Findings:** Significant reductions in relative mean difference lateral position (RMDLP) scores were recorded during the last six segments of the first lap of the track, as compared to the first six, t(29) = 4.98, p <.001, d = .91. Likewise, significant reductions were recorded along the lateral position variance scores from the initial six lap segments, to the final six, t(29) = 3.76, p = .001, d = .69. No gender differences emerged.

**Conclusions:** These findings indicate that young drivers adapt to driving in the simulator during the period of driving a single lap of the simulated track, a distance of 8.89km, completed in approximately 8-10 minutes. This is in line with previous adaptation periods implemented in research, and confirms the findings of the statistical approach adopted.

**Implications:** Young drivers completing any of the drives during the current programme of research must undertake a 8.89 km adaptation drive, to ensure that any measures/results obtained reflect their true driving abilities, rather than difficulties using the equipment.

**C2.3 Rationale for Study 4a: Driving simulator adaptation**

A particularly important consideration when designing experimental protocols for driving simulator research is the incorporation of an adaptation period for inexperienced participants using the novel equipment, to be undertaken prior to commencing experimental sessions (Kane et al., 2004; Purnell et al., 2014; Ronen & Yair, 2013). This period is referred to in numerous additional ways throughout the driving research literature, for example, as ‘accommodation’, ‘training’, ‘familiarisation’, ‘acclimation’ or ‘practice’. The premise for its inclusion is that, in order for the driving behaviours recorded during the simulated drive(s) to be valid, and reflect true driving abilities, drivers must first have had time to ‘adapt and transfer their already existing driving skills to the simulator’ (McGehee, Lee, Rizzo, Dawson, & Bateman, 2004; Saeed & Tarek, 2010, p. 33). Driving in a simulator differs from driving in a vehicle, and providing a period of time to adapt to the simulator facilitates driving behaviours that reflect real-world driving abilities and choices, and not difficulties using the equipment.
The current study focused on providing objective indicators of simulator adaptation through examining measures of young driver lateral position (position on the simulated roadway) and variability of this during the simulated drive. Lateral position variability provides a measure of driving performance that captures the ‘safety relevance of changes in driving behaviour’ (McGehee et al., 2004, p. 185; Ronen & Yair, 2013). That is, it provides an objective indication of the extent of participant control over the simulated vehicle, and is considered an optimal measure through which to examine participant adaptation. As this was an exploratory study, no specific hypotheses were proposed. Based on previous research however, it was anticipated that adaptation would occur within a maximum of 15 minutes of commencing driving (Ba, Zhang, Salvendy, Cheng, & Ventsislavova, 2016; McGehee et al., 2004).

**C2.3.1 Method**

**Participants**

The sample consisted of 30 young driver participants (fifteen male, fifteen female). A GPower analysis (Faul, Erdfelder, Lang & Buchner, 2007) indicated that a sample of 34 participants would be sufficient to identify any significant changes over time at \( \alpha = .8 \), and an anticipated medium effect size. At \( n = 30 \) however, significant differences were detected. Ten completed the adaptation study, and adaptation drive data from a further 20 was extracted from young drivers completing Studies 5 \( (n = 10) \) and 6 \( (n = 10) \) and included in final analyses. All \( (n = 30) \) had normal (or corrected to normal) vision, were currently insured, and were students at the National University of Ireland, Galway, with a reported mean age of 21.1 years \( (SD = 1.75) \). Participants were fully licensed drivers, with an average of 2.66 years of licensed driving experience \( (SD = 1.61) \). Thirty-three per cent \( (n = 10) \) had driven a car ‘earlier today’, 20% \( (n = 6) \) had ‘driven yesterday’, 37% had driven during the last week \( (n = 11) \) and 10% \( (n = 3) \) had driven within the last year or more. Twenty of the participants \( (67\%) \) drove their own car, and ten \( (33\%) \) drove cars belonging to their parents. Two of the participants \( (7\%) \) had driven in a different driving simulator before for 0-2 hours as part of a research study.

**Materials**

**Driving Simulator.** A desktop driving simulator was sourced and purchased from Carnetsoft™ in the Netherlands. The simulator (pictured in Figure 11 below) consists of Carnetsoft simulator software, a Logitech steering wheel (featuring an ignition key and indicators), pedals (i.e. accelerator, brake and clutch) and a gear stick (featuring six forward
Three, 32-inch, SONY HD TV screens provide a forward, right and left view within the simulated car. Simulated drives are rendered across the three HD monitors with 210 degrees horizontal field of view, at approximately 60 images per second. This equipment was mounted on a faux leather covered table (to create a ‘dashboard’ look), and a leather Opel Corsa car seat was obtained and secured to a painted steel frame to facilitate seat adjustment for participants. Carnetsoft simulator software has been used extensively in driving simulator research (e.g. de Waard, Dijksterhuis, & Brookhuis, 2009; de Waard, Kruizinga, & Brookhuis, 2008; Van Winsum & Brouwer, 1997; Winsum & Heino, 1996), and records 10 measurements of any selected continuous dependent variables per second.

**Simulated Drive.** A driving scenario 26.67km in length (featuring three, identical laps of one 8.89km rural road track) was created. This was anticipated to take an average of 25 - 30 minutes to complete, ensuring that adaptation would have taken place during this (the majority of existing simulator studies suggest that this occurs within a maximum of 15 minutes of driving; Ariën et al., 2013; Ba et al., 2016; McGehee et al., 2004; Ronen & Yair, 2013). The drive consisted of a rural, Irish road, featuring both curved and straight segments of roadway, no traffic, and a series of differing speed limits (60km/h, 80km/h and 100km/h). This drive was an extended version of the 8km drive to be used in the subsequent SDSS experimental research studies for the current programme of research. This was selected to ensure that participants would have adapted to the exact driving scenarios they would experience during their baseline and experimental drives. Ten participants completed the 26.67km drive, and the point of adaptation to the simulator identified. Data from a further 20 participants were then extracted from their subsequently specified adaptation drives (featuring the same track, same instructions etc.) that they completed prior to their baseline drives during Studies 5 (n = 10) or 6 (n = 10).
Dependent Variables

Lateral Position. As in previous simulator studies (e.g., McGehee et al., 2004; Montella et al., 2011; Ronen & Yair, 2013; Rosey & Auberlet, 2014; Saeed & Tarek, 2010), measures relating to lateral position were taken as the primary outcome variables. Mean lateral position scores (10 recorded per second) were plotted against an optimal lateral position line (the optimal lateral position score is 3.35m) to demonstrate adaptation over time. Relative mean difference lateral position (RMDLP) scores were then determined for each participant by comparing their mean lateral position score to 3.35m, and calculating their absolute distance from this. Significant reductions in this score over time were taken to indicate adaptation. Lateral position variability (i.e. variance) was also examined. Variance scores were calculated for each segment of the three laps (each identical lap had 44 segments) within the simulated drive. These scores were primarily examined graphically for the first 10 participants, and were subject to inferential statistics when n = 30.

Demographic Variables. A questionnaire was designed to gather participant demographic information including age, gender etc. This also contained a series of driving-related questions such as: when the participant last drove, when they obtained their full driving licence (see Appendix F), in addition to an item assessing whether they had driven in a driving simulator before.

Procedure

Data were collected for this study at three different time points. Following a detailed introduction and demonstration as to how to use the driving simulator (including demonstrations of how to adjust the driving seat, ‘start’ the simulated car, and change gears while driving etc.), ten participants first completed the full 26.67km drive (i.e. three laps of the rural track, taking approximately half an hour). This was to provide an initial assessment, and identify the likely point of simulator adaptation, based on inspections of graphical representations of participant lateral position data. Completing this period of adaptation (i.e. driving for this specified distance) was then required for all participants taking part in any further simulator-based, SDSS efficacy studies (i.e. Studies 5-7). Adaptation drive data was then extracted from an additional 20 participants at random, to validate the initial findings, and ensure higher statistical power when conducting inferential statistics. All participants (i.e. n = 30) received identical, detailed descriptions and demonstrations as to how to use the simulator prior to completing their adaptation drive.
**C2.3.2 Results**

*Data Analytic Strategy*

Mean lateral position, RMDLP and variance scores were the focus of the analyses. For the first ten participants, scores on the first and last six segments for each lap were compared graphically to investigate and identify the point of adaptation (each lap contains 44 segments), as it was anticipated that adaptation could occur within one lap. Following the graphical examination, inferential statistics were then employed to test for significant improvements over the graphically identified adaptation period via a series of paired samples t-tests (using the entire \( n = 30 \) sample). The mean lateral position and RMDLP scores were found to be non-normally distributed (i.e. skew values > .8, and kurtosis values > 3), and were transformed via logarithmic transformation. Results based on inferential statistics provided below are based on these transformed and normally distributed scores.

*Adaptation*

The (untransformed) mean lateral position scores for the first six and last six segments of each lap of the rural track were plotted against an optimal lateral position line (3.35m), and visually inspected (\( n = 10 \)). Likewise, variance scores (as calculated using the variance function in Microsoft Excel) were plotted, and examined. It became apparent that adaptation occurred within the first lap of the rural road track (i.e. mean lateral position scores appeared visibly, consistently closer to the optimal lateral position line, and variance scores were closer to zero; e.g. see Figures 12-13) and so data in relation to the first six (segments 1-6), and last six segments (segments 39-44) of this lap became the focus of analyses. Although not identical, these segment groupings were the most similar in terms of difficulty (i.e. similar numbers of, lengths of, and extents of curved and straight segments), and thus were selected for comparison. Example graphical evidence of adaptation for a participant is provided below via their mean lateral position scores (see Figure 12) and corresponding variance scores (see Figure 13). Of note, segment 44 features a wide turn, with a higher speed limit than the rest of the drive, which may account for the increased variability recorded for this segment in Figure 13. These data trends reflect those plotted for the other nine participants.

Descriptive statistics (untransformed) for the 30 participants evidenced a reduction in RMDLP scores from the first set of six segments (\( M = 1.22, SD = .29 \)) to the last six (\( M = .39, SD = .12 \)). When examining the transformed (normally distributed) scores with paired samples t-tests, this was found to be a large, statistically significant, effect, \( t(29) = 4.98, p < .001, d = .91 \) (where a \( d \) value of .2 denotes a small effect, .5 denotes a medium effect, and .8 denotes a large effect size, Sullivan & Feinn, 2012). Similarly, variance scores were...
also found to decrease significantly from the first set of six segments ($M = .12, SD = .06$) to the last six segments ($M = .09, SD = .05$) on the first lap of the rural track, $t(29) = 3.76, p = .001, d = .69$ (a medium effect).

**Figure 12.** Mean lateral position plotted against optimal lateral position for Participant A.

**Figure 13.** Variance scores for Participant A.

### C2.3.3 Summary Discussion

This study identified a period of adaptation suitable for use in research protocols with the novel driving simulator set-up. Visual inspection of mean lateral position and variance
graphs ($n = 10$) first indicated that young driver adaptation occurred during one lap (8.89km) of the rural road track to be used for subsequent SDSS empirical studies. This was further confirmed through the use of inferential statistics with a 30-participant sample, wherein significant improvements in lateral position scores (i.e. reductions in RMDLP and variance scores) were documented during the first lap. These findings suggest that the implementation of a one-lap drive prior to commencing experimental drives, will ensure behaviour recorded reflects actual driving abilities, skills and choices, rather than difficulties using novel driving equipment.

**C2.4 Abstract Study 4b**

**Background:** In order to ensure that the behaviours recorded in a driving simulator actually represent those conducted on the roads, the behavioural validity of a driving simulator must be ascertained prior to usage in driving experiments. Although Carnetsoft simulation software has been extensively and successfully validated, it has not yet been validated in the context of the specific, low-fidelity, desktop simulator set-up at NUI Galway, necessitating an examination of this at this stage.

**Aims:** This study aimed to evaluate the validity of the novel driving simulator obtained for the purpose of conducting experimental SDSS research at NUI Galway.

**Methodology:** Speed data (mean speed and number of speeding violations) were extracted from 30 young driver participants completing Study 4a ($n = 10$) and Study 5 ($n = 20$). Correlation analyses were conducted to understand the relationship between scores on the ‘Violations and Traffic Rules/Speeding’ subscale (i.e. their risky driving propensity) of the Driver Behaviour Questionnaire (DBQ), and mean speed, and their recorded number of speeding violations.

**Findings:** A significant, large correlation was reported between the DBQ subscale score, and driver mean speed, $r = .65, p < .001$ A significant, medium correlation was also reported between the DBQ score and the number of speeding violations $r = .38, p = .04$.

**Conclusions:** Significant correlations were observed between young driver mean speed, the number of violations they committed during the simulated validation drive, and their DBQ self-report of on-road speed and risk-taking. As such, the NUI Galway driving simulator set-up demonstrated relative behavioural validity, in line with previous validity examinations using Carnetsoft software.
**Implications:** Any speed-related dependent measures recorded in the NUI Galway driving simulator can now be considered as behaviourally valid, and appropriate reflections of those engaged in ‘on-road’.

**C2.5 Rationale for Study 4b: Driving simulator validation**

Simulation must be considered an abstraction of reality that, while representing certain aspects of driving well, disregards others (Molino, Katx, Opiela, & Moyer, 2005). There is agreement across the research literature that ensuring the validity of the behaviours recorded in a driving simulator is an essential component of any simulated driving study (e.g. Shechtman, Classen, Awadzi, & Mann, 2009). Several forms of validity of driving simulators have been identified (Mullen, Charlton, Devlin, & Bédard, 2011). Of greatest importance however, is that the simulated environment elicit the same driving responses and behaviours, as driving on a real-road, i.e. behavioural validity (Risto & Martens, 2014).

Behavioural validity has been further defined in terms of relative and absolute validity. Absolute validity requires that driving measures obtained from the simulator and on-road driving be numerically identical, whereas to establish relative validity, such measures must merely be of similar magnitude and direction (e.g. a significant, positive correlation between the two; Godley, Triggs, & Fildes, 2002; Klüver et al., 2016). Absolute validity is rarely documented in driving simulator studies, but establishing relative validity is deemed sufficient (and necessary) to confirm the value of any driving behaviours measured and recorded, and ensure the accuracy of any findings reported. Thus, it is crucial to establish the relative validity of any novel driving simulator, to ensure that it measures what it is supposed to measure, and does not lead to false conclusions regarding the objectives of research studies.

Carnetsoft driving simulator software has been previously validated and used in driving research (e.g. de Waard et al., 2009; de Waard et al., 2008; Van Winsum & Brouwer, 1997; Winsum & Heino, 1996). Such studies have generally featured different simulator equipment however, and typically of higher fidelity than the NUI Galway set-up. Although the NUI Galway simulator set-up was designed to maximise ecological validity and fidelity (e.g. the use of a real car seat, creation of a ‘dashboard’; see Figure 15 above), overall, desk-mounted simulators are recognised as retaining less behavioural validity than moving-base, set-ups (e.g. Klüver et al., 2016). Given such limitations, in order to ensure the reliability and
accuracy of any driver behaviour-related findings produced by the current programme of
research (i.e. findings from Studies 5-7), a validation study was conducted.

While validation research has focused on an array of outcomes, driver speed has been
frequently examined in relation to such studies (e.g. Bham, Leu, Vallati, & Mathur, 2014;
Godley et al., 2002; Klüver et al., 2016; Meuleners & Fraser, 2015; Törnros, 1998). As one of
the main aims of the current programme of research is to assess the impact of SDSS use on
young driver speed (specifically, mean speed, and speeding violations), it was considered
particularly appropriate to adopt this as the study outcome for the validation study. In
addition, for feasibility purposes, it was decided that driver self-report measures of on-road
speed would be compared to simulated driving behaviours here, instead of on-road measures
(Taubman-Ben-Ari, Eherenfreund – Hager, & Prato, 2016). The Driving Behaviour
Questionnaire (DBQ; Iversen, 2004) ‘Violation of traffic rules/speeding’ subscale was
selected as a comparison, given that the DBQ has been studied extensively, and is regarded as
a valid indicator of on-road driving (de Winter & Dodou, 2010; Helman & Reed, 2015).

The following hypothesis was explored:

1. There will be a significant, positive correlation between the DBQ violations subscale
   score, mean speed and number of speeding violations recorded in the driving simulator.

C2.5.1 Method

Participants

Data from 30 participants (14 male, 16 female) were extracted from the adaptation
(Study 4a, n = 10) and monitoring (Study 5, n = 20) studies. A GPower analysis (Faul et al.,
2007) indicated that a sample of 34 participants would be sufficient to identify any significant
changes over time at α = .8, and an anticipated medium effect size. At n = 30 however,
significant differences were detected. Data were extracted from these particular studies as
these involved comparable drives suitable for validation analyses. All participants were aged
between 18-24, had their full Irish driving licence, used a smartphone and were currently
insured. All had normal (or corrected to normal) vision, and were students attending NUI
Galway. Participant mean age was 21.3 years (SD = 1.64), and on average, drivers had been
licensed for approximately 2.46 years (SD = 1.42). Thirty-three per cent (n = 10) had driven a
car ‘earlier today’, 20% (n = 6) had ‘driven yesterday’, 30% (n = 9) had driven within the last
week, 7% (n = 2) had driven within the last month, and 10% (n = 3) had last driven within the
last year or more. The majority owned their own cars (57%, n = 17), 40% drove their parent’s cars (n = 12), and one participant drove a vehicle belonging to their sibling (3%).

Materials

Driving Simulator. The same desktop driving simulator as described in Study 4a was utilised for this study.

Simulated Drive. For participants whose data were extracted from the adaptation study (n = 10), this was taken from the 25-minute, three-lap adaptation drive that they completed. In total, 8km of data were extracted following 8.89km (i.e., so that they had completed one lap, had adapted to the simulator and were driving as they normally would for the next 8km). Data from 20 participants were extracted from Study 5 (see Chapter 7), where, having completed an initial adaptation drive, young drivers then completed an 8km drive, during which they were informed to drive as they normally would. Thus, both groups of participants (i.e. those from the adaptation [Study 4a] and monitoring [Study 5] studies) drove identical 8km tracks, as they normally would, rendering them suitable for comparison with the DBQ self-report measure. The 8km distance was selected, as a recent travel study conducted in NUI Galway confirmed that this distance was the most common daily journey made by young student drivers to campus (Lipscombe & Power, 2012).

Dependent Variables

Driver Behaviour Questionnaire. As described in Study 2 (Chapter 4), the DBQ ‘Violations of Traffic Rules/Speeding’ subscale (six items) was employed in the current study to provide an indication of risky driving propensity. Responses were recorded on a five-point Likert scale (ranging from 1 ‘never’, to 5 ‘very often’). Higher DBQ subscale scores indicated higher levels of reported violations and speeding (i.e. greater risk-taking). Internal consistency of this subscale was good, \( \alpha = .80 \).

Mean Speed. Once specified, the Carnetsoft driving simulator can automatically calculate and provide a measure of overall mean speed (and standard deviation) for a single, completed drive. For participants whose validation drive data came from the total 26.67km adaptation drive (n = 10) however, raw, continuous velocity scores for the 8km, following the initial 8.89km adaptation drive, had to be extracted and mean speed scores calculated in Microsoft Excel. Mean speed scores for the 8km drive completed by participants in Study 5 (n = 20), were automatically generated and ready for use in the validation study.

Number of Speeding Violations. For the purpose of the current programme of research, speeding violations were defined as occurring once a participant had been driving at
a speed 10% above the current limit (e.g. 67km/h in a 60km/h zone), for more than five seconds. Again, once specified, the Carnetsoft driving simulator can automatically count and provide the number of speeding violations that occurred in a single, completed drive. However, in the case of the data gathered from participants from the adaptation study \((n = 10)\), these had to be calculated from extracted velocity scores relating to the 8km drive, drive segment numbers and their corresponding speed limits. The number of speeding violations data were automatically generated for participants who completed an 8km drive as part of Study 5 \((n = 20)\), and were ready for use in the current study.

**Demographic Variables.** As part of their respective studies, each participant completed an identical questionnaire designed to gather participant demographic information including age, gender etc., and also contained a series of driving-related questions such as when the participant last drove, when they obtained their full driving licence etc. (see Appendix F). The DBQ violations/speeding subscale was administered as part of this questionnaire.

**Procedure**

Participants were recruited to take part in either a simulator adaptation study (Study 4a, extracted \(n = 10)\) or a SDSS monitoring study (Study 5, extracted \(n = 20)\). Upon signing a consent form, and being provided with a detailed description and demonstration as to how to use the driving simulator, all participants completed a 8.89km adaptation drive. Upon finishing the drive, participants continued to complete the other aspects of their respective research studies (i.e. Study 4a or Study 5), which involved driving a further 8km ‘as they normally would’. All participants completed the DBQ, and a series of driving-related items upon completion of the driving elements of their respective studies.

**C2.5.2 Results**

**Data Analytic Strategy**

No evidence of distribution non-normality was observed. Correlations between the participants’ DBQ subscale scores, mean speed and number of speeding violations committed during the simulated drive were the main focus of the validation analyses.

**Hypothesis Testing**

**Hypothesis 1.** There will be a significant, positive correlation between the DBQ violations subscale score, mean speed and number of speeding violations recorded in the driving simulator.
Overall, mean speed for the simulated 8km drive across participants ($n = 30$) was reported as 72.09 km/h ($SD = 6.79$km). A correlation analysis between the mean speed selected by the young driver during the 8km drive post-adaptation and their overall DBQ score (where a higher score denotes a riskier driver) was first conducted. This was found to be a ‘large’ significant correlation, $r = .65$, $p < .001$ (Field, 2009). Likewise, a significant correlation was reported between DBQ scores and the number of speeding violations committed while driving in the simulator, $r = .38$, $p = .04$ (a medium correlation). These are depicted on scatterplots (Figures 14 and 15) below.

*Figure 14.* Scatterplot demonstrating the significant, positive correlation between DBQ scores and mean speed during the simulated drive.

*Figure 15.* Scatterplot demonstrating the significant, positive correlation between DBQ scores and number of speeding violations during the simulated drive.
C2.5.3 Summary Discussion

Significant correlations were observed between young driver mean speed, the number of violations they committed during the simulated validation drive, and their DBQ self-report of on-road speed and risk-taking. This indicates that the current Carnetsoft driving simulator set-up in NUI Galway provides a valid reflection of participants’ reported ‘real-world’ driving, particularly speed, which is the focus of the current programme of research. Establishing the relative behavioural validity of this driving simulator facilitates proceeding to testing the SDSS empirical studies of the current programme of research, in the knowledge that speed-related measures provided by the simulator are appropriate reflections of on-road driving.

C2.6 Contribution and Conclusions

The findings of these two simulator studies suggest that participants adapt to the NUI Galway driving simulator set-up and rural road track following a one-lap (8.89km) drive of the rural road track. This established adaptation period can now be completed by each participant taking part in subsequent SDSS studies (Studies 5-7), to ensure driving measurements provided by the simulator are accurate and reflect actual driving abilities and choices. In addition, the relative behavioural validity findings of Study 4b have attested that the speed variables measured and recorded in the NUI Galway driving simulator with the Carnetsoft software are valid reflections of reported on-road driving. Although the comparison of on-road measures of speed with simulator driving could further enhance this finding, at present, these results provide sufficient justification to proceed with using the specified adaptation period and particular simulator set-up for the purpose of completing the proposed SDSS empirical studies within this programme of research.
Chapter 7 - Section C3: Examining the Impact of a SDSS that Monitors Driving on Young Driver Speed.

C3.1 Abstract

**Background:** The findings of Study 3 suggested that in-vehicle monitor use can improve young driver behaviour, however, this has yet to be empirically examined in the context of SDSS use. Research on the Hawthorne effect, and observations during IVDR studies, suggest that SDSS monitoring alone may impact upon driving behaviour. It is not yet clear as to whether this is the case however, what theoretical mechanisms underlie this effect, and whether individual difference variables may moderate this.

**Aims:** This study aimed to investigate: 1) the impact of SDSS monitoring on young driver speed in a simulated environment; 2) whether the theory of Self-Regulation (SR) underlies this, and; 3) whether efficacy was moderated by individual difference variables (trait SR, and Fear of Negative Evaluation [FNE]).

**Methodology:** Forty-two young driver participants with full Irish driving licenses and current insurance completed a combined adaptation and 8km baseline drive (Time I), and were then randomly assigned to either drive 8km with a monitoring SDSS (Time II), or complete a second ‘practice’ 8km drive without a SDSS (i.e. the control condition). Following this, all participants completed a SR Stroop task measure, and a detailed participant questionnaire, recording demographic and driving history variables, and trait SR and FNE measures.

**Findings:** The implementation of a monitoring SDSS was found to significantly reduce mean speed from Time I to Time II, t(18) = 2.72, 𝑝 = .01, 𝑑 = .63. A significant main effect of time and condition also emerged for the number of speeding violations variable, with significant reductions being reported for those in the monitoring group only, t(18) = 3.59, 𝑝 = .01, 𝑑 = .82. There was no evidence of SR underlying these effects, or any moderation of these findings by the individual difference variables.

**Conclusions:** The current findings suggest that SDSS monitoring can reduce young driver mean speed, and their number of speeding violations in a simulated driving environment. The theory of SR may underlie this effect, but further investigation is needed to ascertain this.

**Implications:** The use of a monitoring SDSS alone improves young driver risk-taking, indicating that more complex features (e.g. the provision of real-time feedback and/or a financial incentive) may improve upon this further, and should be investigated.
C3.2 Introduction

This section presents the findings of the first of three experimental studies on the impact of SDSS usage on young driver behaviour. The central research question for this first experiment was: does SDSS monitoring have an impact on young driver speed? Subsequent experiments (Studies 6 and 7) expand on this by examining the impact of a monitoring SDSS combined with real-time feedback functionality and/or a financial incentive (Study 6, Chapter 8), and by examining the impact of engaging with real-time SDSS feedback on driver distraction (Study 7, Chapter 9).

The best research available, synthesised earlier in this thesis (Study 3, Chapter 5), suggests that the provision of IVDR monitoring and feedback (as could be provided by a conceptually similar SDSS) has the potential to reduce young driver speed (e.g. Bolderdijk et al., 2011; Creaser et al., 2009; Farmer et al., 2010). Such findings are inconsistent across studies however, with few examining the efficacy of different monitor features (e.g. the impact of monitoring alone, versus the impact of monitoring plus real-time feedback alerts) involved in usage. Many have also reported small decreases (e.g. Bolderdijk et al., 2011), or no change and increases in measures of risk-taking for certain monitored groups over time (e.g. Farmer et al., 2010). Moreover, this body of research is almost exclusively related to traditional IVDR technologies, and the generalisability of such findings to the topic of SDSS use is uncertain. These studies are also largely atheoretical and lack methodological robustness.

Against this backdrop, this study aimed to establish a ‘proof of principle’ for SDSS efficacy, and address an initial question for SDSS technology: Does SDSS monitoring, in the absence of additional mechanisms of change, have an impact on young driver speed?

C3.3 Rationale for the current study

This study sought to extend the current young driver monitoring literature, by examining SDSS-specific monitoring efficacy, addressing conceptual and theoretical gaps in the literature, and previous methodological concerns from monitoring research studies conducted to date.

C3.3.1 The need for targeted SDSS research. In order to ensure that SDSSs are effective, and identify means through which to maximise any such effects to improve outcomes for vulnerable young drivers, thorough efficacy evaluations of this unique technology are necessary. This first SDSS empirical study began to address this, by seeking
to provide a ‘proof of principle’, and advance beyond pilot evidence (e.g. Creaser et al. 2009) and IVDR studies conducted to date (e.g. Simons-Morton et al., 2013; Musicant & Lampel, 2010), to test the specific influence of SDSS monitoring alone on young driver speed in a simulated environment. It focused on the short-term, immediate impact of driving with a novel SDSS, to provide indications of efficacy when driving with a newly-downloaded app. This study also focused on speed-related, outcome variables (specifically mean speed, and number of speeding violations), given that speed is linked to young driver engagement in extreme manoeuvres (the majority involve improper speed use) and the likelihood of a RTC, and severity of injury, should a RTC occur (Gheorghiu et al., 2015). Fully licensed young drivers were selected as the sample of interest here, as they are more likely to drive alone and benefit most from monitoring technology, as Irish law requires that provisionally licensed drivers drive with an experienced driver present.

**C3.3.2 Identifying mechanisms of change.** Given that research in other domains suggests that monitoring alone may have a ‘Hawthorne effect’ or prompt self-monitoring processes to evoke behaviour change (e.g. Lehmann, 1996; Lehmann & Cheale, 1998; McCambridge et al., 2014), but that this has typically not been examined in young driver IVDR studies, it was necessary to elucidate this before examining the combined impacts of monitoring and feedback and/or financial incentives. In addition, at present, a number of SDSSs are commercially available via the App Store or Google Play for young drivers in Ireland that provide monitoring alone to the user in real-time (i.e. the app solely monitors driving in-vehicle, and then creates personal records over time), yet the efficacy of this kind of SDSS has not been established.

In line with this, to date, the theoretical mechanisms underlying the efficacy of SDSSs are largely unknown. These are proposed to relate to SR and OC, although SR is primarily relevant in the context of SDSS monitoring alone (OC is of relevance when reinforcement via feedback and/or financial incentives, for example, is provided). As such, this current study also strove to address identified theoretical and conceptual gaps in the greater driver monitoring literature, by examining whether the theory of SR underlies the monitoring SDSS efficacy process. Of note, SR is understood to involve a limited resource, such that when an individual regulates their behaviour during a task, they experience depletion of the SR resource, and their ability to self-regulate on a subsequent task is impaired (Baumeister, 2014; Gailliot et al., 2007; Hagger, Wood, Stiff, & Chatzisarantis, 2010). As such, it should be possible to infer whether SR has taken place during a task, by examining performance on a second SR task after it (i.e. performance on the second task is impaired to the extent that SR
was exerted on the previous one). In the absence of an existing state SR measure, for the purpose of this study, a measure of state SR was designed and calculated by examining performance on a typical SR task (specifically, a Stroop task, e.g. Marsh et al., 2006; Webb, 2008) immediately following the Time II drive. Whether this state SR score moderated the efficacy of the SDSS monitor was then examined, to provide evidence of the theory of SR in evoking SDSS-related behaviour change. Last, this study also analysed whether a number of relevant, personality-related variables (including trait SR, and FNE as highlighted in Chapter 5) potentially moderate the impact of SDSS monitoring on behaviour.

C3.3.3 Addressing methodological issues. An array of limitations in previous young driver monitoring studies (see Section C1.5, Study 3) renders it difficult to draw any definitive conclusions regarding SDSS efficacy at present. In aiming to address previous methodological issues within the research literature, this study first, employed a control group for comparison, to ensure that any observed effects were due to the implementation of SDSS monitoring alone. It incorporated equal numbers of male and female participants, with an age range of 18-24 years to encompass the entire, and gender-balanced, high-risk driving demographic. This research was also conducted in a driving simulator to ensure that all participants experienced controlled, identical conditions, with scripted instructions, in a safe driving environment. Last, it also included measures of a series of psychological variables (mood, self-efficacy and motivation) to ensure there were no differences between the experimental and control group drivers along such constructs that could be influencing SR at different points in the experiment (Furley, Bertrams, Englert, & Delphia, 2013).

Thus, the current study employed a two-group, RCT design that aimed to compare young driver speed (i.e. mean speed, and number of speeding violations) between groups (i.e. those driving with the SDSS, and those driving ‘as normal’ in the control condition), and over time (i.e. two timepoints including a baseline and experimental drive). The following hypotheses were explored:

1. Participants who were informed that their speed would be monitored by the SDSS will show significantly greater reductions in mean speed and speed violations (pre to post), than those in the control group.
2. State SR will moderate the impact of SDSS condition on speed (mean speed and number of speeding violations).
3. Trait SR and FNE will moderate the impact of SDSS condition on speed.
C3.4 Method

Participants

The sample was recruited predominantly from a 2nd year Social Psychology module within NUI Galway. Students were required to attain research participation credits to complete the module, and this study was advertised as one means to fulfill this requirement, among others. Social media (e.g. Facebook and Twitter), email and on-campus poster campaigns were also utilised to advertise the study to prospective participants in the Galway area. Those completing the experiment as part of their Social Psychology module received two credits, and any other participants were informed that they would be reimbursed with €10 for their time. All participants, regardless of reimbursement type, were randomly allocated to groups. All advertising materials informed the reader that only individuals with a full Irish driver’s licence, current insurance and smartphone, aged between 18-24 would be eligible to take part.

Following the removal of a number of justified outliers \((n = 8; \text{ e.g. where participants were over the age for the inclusion criteria, but did not disclose this until after testing, or when participants disclosed they had purposefully crashed the simulator on a number of occasions to ‘see what would happen’) the total sample comprised of 42 participants, 20 male (48%) and 22 female (52%). A GPower analysis (Faul et al., 2007) indicated that a sample of 34 participants would be sufficient to identify any significant changes between groups, and over time, at \(\alpha = .8\), and an anticipated medium effect size. Mean participant age was 20.57 years \((SD = 1.55)\) and participants had been fully licensed for an average of 2.15 years \((SD = 1.23)\). A total of 41 of the young drivers identified as students (98%), with just one individual working full or part-time (2%). Twenty (48%) of the drivers personally owned their own car, with 22 (52%) driving vehicles belonging to their parents or siblings. Three (7%) of the drivers had received penalty points in the past 3 years, all of which were for speeding, and six (14%) reported previously racing against another driver on a public road. Eleven participants (26%) had last driven a car earlier that day, with nine (21%) reporting driving yesterday, fourteen (33%) last driving within the past week, and four (10%) having driven in the last month. Two (5%) had driven in the last year, and a final two participants had driven more than one year ago. All participants had normal or corrected to normal vision.

Materials

Driving Simulator. Participants completed the drives of this study using the NUI Galway Carnetsoft driving simulator described in detail in Studies 4a + b, Chapter 6.
Simulated Drives. As per the findings of Study 4a, participants were required to complete a one-lap, adaptation drive prior to completing any experimental measures. Thus, three drives in total (i.e. adaptation, baseline Time I and experimental Time II) were completed as part of the current study. These drives were the same, rural Irish track, featuring both curved and straight segments of roadway, no traffic, and a series of differing speed limits (60km/h, 80km/h and 100km/h) identical to those featured in Studies 4a and b. It was decided to combine the initial adaptation and baseline drive, such that participants would adapt to the simulator, and then simply continue to drive to complete the baseline Time I measure. The initial drive completed by the participants thus consisted of the 8.89 km adaptation drive, and 8 km Time I drive (i.e. 16.89 km total) which took approximately 15-20 minutes. After this, they received their condition-specific instructions and completed the last drive (experimental Time II), which was an identical 8km track to the baseline drive, taking between 8-10 minutes to complete.

Smartphone Driver Support System. For the purpose of the current study, which investigates the impact of SDSS monitoring alone (i.e. no feedback) in a driving simulator, a functioning SDSS was not required to facilitate experimentation. Participants in the experimental condition were informed that their speed was going to be monitored by a SDSS, however, the driving simulator would actually provide records of their driving behaviour for analysis. An iPhone 4s with a SDSS monitoring ‘interface’ (this was a single, saved image displayed on the phone as a screensaver, see Figure 16 below) belonging to the principle researcher was used, and docked in an EX Spider iHolder (see Figure 11 above). Prior to the commencement of the monitoring drive (for those randomly assigned to the monitoring condition), the phone was placed to the left of the centre screen (mimicking the location where a smartphone would actually be placed to be docked on a dashboard), with a connecting cable plugged into it. This cable was actually an iPhone charging lead, and was then discreetly plugged into an electrical socket by the researcher whereupon it vibrated audibly, and the participant was informed that this meant the SDSS was ‘active’.

Dependent Variables - Speed Measures

Mean Speed. As described in Study 4b, the Carnetsoft driving simulator can automatically calculate and provide an output measure of mean speed (and standard deviation) for a single, completed drive (e.g. the experimental Time II drive). Given that the adaptation and Time I drives completed by participants were combined in the current study however, the mean speed value provided was not suitable for use, as it encompassed mean
speed across the two drives in total. Raw, continuous velocity scores for the combined drives recorded by the driving simulator were examined, and scores relating solely to the 8km Time I drive extracted, and used to calculate means speed scores for the Time I drive. Time II scores were automatically generated and ready for use.

**Number of Speeding Violations.** Similarly, in the case of the first drive (consisting of the adaptation and baseline Time I drive) completed by participants, the number of speeding violations score provided by the driving simulator was not appropriate for use. A series of excel formulas were then derived to calculate the number of speeding violations for each participant during the Time I drive specifically, which was primarily dependent on extracted raw velocity scores, drive segment numbers and their corresponding speed limits.

**Dependent Variable - SR Measure**

**Stroop Task - State SR.** Participants completed a standard Stroop task using PsychoPy software on a 13-inch MacBook Pro to provide a measure of SR depletion (i.e. the state SR score). They received scripted vocal instructions from the researcher informing them that they would be presented with a series of words on the computer screen, and that they would be required to press a button to identify the colour that the word was printed in (and not respond to the word itself) as quickly as possible. They were shown that the response buttons had the appropriate colours (red, blue or green) pasted over them. This was reiterated via on-screen instructions once they began the Stroop task. A brief practice session was provided first, which presented a total of 12 stimuli, including 6 congruent (i.e. word and colour matching, e.g. the word ‘green’ presented in a green font) and 6 incongruent stimuli
(i.e. word and colour mismatching, e.g. the word ‘red’ presented in green font) in random order. Simple on-screen feedback was provided for the practice trial after each response (e.g. ‘Correct! Reaction time = X’ or ‘Oops! That was wrong’). Once this was over, the on-screen instructions were shown once more. Participants then completed the full Stroop trial, which featured 60 stimuli (30 congruent and 30 incongruent) and appeared in random order. Reaction time, and number of correct responses, were recorded by the PsychoPy software. The Stroop interference (i.e. depletion) score was calculated by subtracting the mean reaction time for the congruent stimuli from the incongruent stimuli, such that larger, positively valenced scores indicated greater interference (and depletion from the Time II drive). This was taken as a measure of state SR during the Time II drive.

**Moderator Variables**

**Short Self-Regulation Questionnaire - Trait SR.** Participants completed the Short Self-Regulation Questionnaire (‘SSRQ’; K. B. Carey, Neal, & Collins, 2004), a 31-item measure of trait SR. This is based on the original Self-Regulation Questionnaire (‘SRQ’; Brown, Miller, & Lawendowski, 1999) designed to assess SR capacity across seven SR processes. The SSRQ contains statements regarding participant SR (e.g. ‘I set goals for myself and keep track of my progress’), and utilises a five-point Likert type response format (ranging from 1 ‘strongly disagree’, to 5 ‘strongly agree’). Following reverse coding of any reverse keyed items (e.g. ‘It’s hard for me to notice when I’ve had enough [alcohol, food, sweets]), scores are summed to provide a scale total. The internal consistency of the SSRQ in this sample was good, $\alpha = .93$.

**Brief Fear of Negative Evaluation - FNE.** The Brief Fear of Negative Evaluation (‘BFNE’; Leary, 1983) questionnaire is a 12-item scale designed to assess the extent to which the individual fears being negatively evaluated by others. Items include concerns such as ‘I am afraid that others will not approve of me’ or reverse-keyed items such as ‘I am unconcerned even if I know people are forming unfavourable impressions of me’. A 5-point Likert scale is employed for responses, ranging from 1 ‘Not at all characteristic of me’ to 5 ‘Extremely characteristic of me’. Cronbach’s Alpha indicated that this had good internal consistency for this sample, $\alpha = .89$.

**Additional Variables**

**Brief Mood Introspection Scale.** The Brief Mood Introspection Scale (‘BMIS’; Mayer & Gaschke, 1988) was employed in the current study pre and post the Time II drive, and pre the Stroop task to ensure no mood fluctuations were responsible for any differences observed
in mean speed, speeding violations or Stroop scores across these three time points. This is a 16-item scale (with ‘pleasant’ and ‘unpleasant’ subscales) wherein participants are instructed to indicate how well the adjectives or phrases (on a pleasant or unpleasant presented describe their current mood (e.g. ‘lively’, ‘tired’, or ‘gloomy’)). These are recorded on a 4-point Likert scale from 1 ‘Definitely do not feel’ to 4 ‘Definitely feel’. The scores for the pleasant mood words are summed, as are the unpleasant mood word scores, which were then subtracted from the total pleasant mood words score to provide the final mood score. Internal consistency of the subscales was good, pleasant \( \alpha = .78 \), unpleasant \( \alpha = .75 \) (pre Time II drive), pleasant \( \alpha = .80 \), unpleasant \( \alpha = .85 \) (post Time II drive), pleasant \( \alpha = .80 \), unpleasant \( \alpha = .82 \) (pre Stroop).

**Self-efficacy.** Self-efficacy was measured by a two-item scale adapted from Furley et al. (2013). Participants rated these items (e.g. ‘How successful do you think you were in your most recent drive?’) on a 5-point Likert scale ranging from 1 ‘Not at all’ to 5 ‘Very much so’, following the Time II drive. This too was adapted and completed following the Stroop task. Acceptable internal consistency was reported for both, \( \alpha = .59 \) (driving-related), and \( \alpha = .62 \) (Stroop-related).

**Motivation.** A single item to measure participant level of motivation with regards to driving with the SDSS, and completing the Stroop task was adapted from Dang, Dewitte, Mao, Xiao, and Shi (2013). This was ‘How motivated were you to perform well on the driving task you just completed?’ and ‘How motivated were you to perform well on the computer task you just completed?’. Responses were recorded on a 5-point Likert scale ranging from 1 ‘Not at all’ to 5 ‘Very much so’, following the Time II drive and Stroop task. An open-ended item asking participants to ‘describe their motivation’ in completing the most recent drive, and the computer task was also included.

**SRE - Self-Report State SR.** A three-item self-regulatory exertion (SRE) measure was adapted from Furley et al. (2013), to measure self-report state SR to compliment the state SR Stroop measure. Participant responses to the three items following the Stroop task (e.g. ‘Thinking about the computer task, how difficult did you find it?’) were recorded on a 5-point Likert scale ranging from 1 ‘Not at all’ to 5 ‘Very much so’. Cronbach’s Alpha reported acceptable internal consistency for the SRE items, \( \alpha = .64 \).

**Demographic Variables.** Following completion of the simulated drives and Stroop task, participants completed a brief survey (see Appendix F). This primarily featured a series of demographic items (e.g. age, gender etc.) and a number of driving-related questions (e.g.
When did you last drive a car’, or ‘In the last three years, how many penalty points have you received?’). It also included the DBQ, SSRQ and BFNE measures.

**Driver Behaviour Questionnaire.** As in Study 2 (Chapter 4), of main interest to the current study was the DBQ ‘Violations of Traffic Rules/Speeding’ subscale (six items). Responses were recorded on a five-point Likert scale (ranging from 1 ‘never’, to 5 ‘very often’). Higher DBQ subscale scores indicated higher levels of reported violations and speeding (i.e. greater risk-taking). Internal consistency of this subscale was good, $\alpha = .80$.

**Acceptance.** Participants in the experimental condition were also asked to complete a two-item measure of intention to use a SDSS like the one described to them prior to the Time II drive, if this was made available to them in future. Responses to the following items ‘I want to use this SDSS’ and ‘I intend to use this SDSS’ were made using a 5-point Likert scale response (ranging from 1 ‘strongly disagree’, to 5 ‘strongly agree’). Internal consistency of this measure was good, $\alpha = .91$.

**Procedure**

The experimental procedure is presented in brief in Figure 17 below. This is described in more detail in the following paragraphs.

All participants were allocated an individual time slot at which to arrive at the driving simulator laboratory in the School of Psychology building, on the NUI Galway campus. Upon arrival, they were greeted by the researcher and asked to sit at a desk to the front of a room partition. Participants who were receiving payment for taking part were given an envelope containing €10 at this point, and those completing the study for course credit were informed that they had earned this. All participants were then provided with a detailed participant information sheet to read and were encouraged to ask any questions they may have had regarding the study and participation procedure. Once satisfied with this, they were asked to sign the participant consent form. Those who had received the €10 payment were also asked to sign a receipt confirming they had received this at this point.

Once the consent form had been signed, the participants were brought beyond the room partition to the driving simulator. They were instructed to take a seat ‘behind the wheel’ in the driving seat, in front of the simulator set-up. They were given a standard, detailed verbal introduction to the driving simulator, including demonstrations of how to adjust the driving seat, ‘start’ the simulated car, and change gears while driving etc.
Once any further questions regarding the simulator had been expressed and answered by the researcher, participants were informed that their first drive (Adaptation and Baseline [Time I]) was merely for them to get used to driving the simulator, and that it was not being recorded for the purposes of the study. The drive was described in detail to them (i.e., that it was a rural track, featuring no other drivers, with a starting speed limit of 100km/h, taking about 15 minutes to complete). They were instructed to drive as they normally would. The researcher left the room to complete other work while the participant was driving, so that
drivers did not feel they were being observed. Participants were instructed to press a wireless doorbell beside the simulator once the drive had been completed to alert the researcher that the drive was over, and to re-enter the room.

Participants were then randomly assigned to either the ‘Monitoring’ or ‘Control’ condition. Those in the control group were informed that their next drive (Time II) would be completed to ensure they were fully comfortable with the equipment and that it was not being recorded as part of the study. In comparison, those in the monitoring group were told they would be completing their next drive using a smartphone application that would monitor and record their speed (the SDSS) on the phone. At this point the researcher placed the SDSS in front of the simulator, in a location designated to emulate where a smartphone would be docked in an actual vehicle, and plugged it in. This was discreetly triggered to audibly vibrate to signify that it was ‘activated’, which the participant was informed of. The drive was described to participants again (i.e. a rural road, no other cars present, starting speed limit was 100km/h, taking about 8-10 minutes to complete).

Before beginning the Time II drive, both groups were asked to fill in a mood questionnaire (the BMIS; Mayer & Gaschke, 1988), and the monitoring group also filled in a 2-item measure of SDSS acceptance (e.g. ‘I want to use this app’). Again, they were encouraged to drive as they normally would. Once more, the researcher left the room during the drive, and participants were instructed to press the wireless doorbell once the drive had been completed to alert the researcher that the drive was over, and to re-enter the room.

Immediately following the completion of the second drive, participants were asked to take a seat at a nearby table to complete a ‘computer task’ (the Stroop task). The Stroop task was briefly described with standard instructions, and prior to commencing this, participants completed a second mood measure, and a series of brief items to ascertain participant self-efficacy and motivation. Participants were instructed to start the Stroop task themselves as soon as they had finished the questionnaire. The researcher waited on the other side of the room partition during this time. Once they alerted the researcher that they were finished, they were provided with a third mood questionnaire, and a series of measures assessing the perceived difficulty, effort, and suppression experienced by the participant during the Stroop task (i.e. the SRE: the self-report state SR measure). A series of brief items to ascertain participant self-efficacy and motivation with regards to the Stroop task were then completed.

Following this, they were brought out to a desk set up in the corridor beside the simulator lab to complete a final questionnaire booklet, primarily collecting information on demographic and driving-related variables. This was to ensure that they did not feel they
were being observed while marking their answers (as, for example, some of these included measures of risky driving), and also so that there was adequate time to prepare the driving simulator before the next scheduled participant arrived to take part. This took approximately 10 minutes to complete. Following this, each participant was debriefed orally (i.e. they were informed that their first drive was actually recorded, and the true purpose of the Stroop task was explained), and asked to sign a retrospective consent form to signify their willingness for their data to be used in the study, and potentially in the adaptation and validation studies (Studies 4a + 4b, Chapter 6).

C3.5 Results

Data Analytic Strategy

Before commencing statistical analyses, participant data were first assessed for any missing values. Following this, the normality of all distributions was examined, where, in the event of any evidence of non-normality, appropriate data transformations were applied (as per criteria outlined in Study 2, Chapter 4). In this case, no missing data were noted, and square root transformations were solely applied to the Time I and Time II speeding violation variables in preparation for analyses. In order to better understand the data trends, descriptive statistics (means and standard deviations) for all measures of interest were first calculated for each condition, and at each time point. A series of preliminary one-way Analysis of Variance (ANOVA) analyses were then conducted to ensure there were no significant differences between the groups at baseline, i.e. that participants had been successfully randomised to groups. A correlation matrix was also prepared, to provide an initial indication as to potential moderators for later analyses, and the general relationships between the measured variables. In addition, a series of mixed factorial ANOVAs were used to assess any differences in mood, self-efficacy and motivation between the two groups, and across the different time points.

The main hypothesis (Hypothesis 1), that participants who were informed that their speed would be monitored by the SDSS would show significantly greater reductions in mean speed and number of speeding violations (pre to post), than those in the control group, was tested using a mixed factorial ANOVA with first, mean speed, and second, the number of speeding violations, as outcomes. Post hoc, paired sample t-tests further explored these relationships. For partial $\eta^2$ effect sizes, a value of .01 was deemed small, .06 represented a medium, and 0.14 a large effect size (Field, 2009). For paired samples t-tests, Cohen’s $d$ was
calculated, wherein a value of 0.2 denotes a small effect, 0.5 denotes a medium effect, and 0.8 denotes a large effect size (Sullivan & Feinn, 2012).

To assess whether SR was exerted during the monitored drive (Hypothesis 2), the state SR score was examined as a potential moderator of SDSS monitoring efficacy. The Stroop interference score was taken as a state SR variable (indicating the extent to which SR was exerted during the Time II drive), and entered into a hierarchical, multiple regression equation. This process was then repeated using the self-report SRE score. Last, to assess whether any other potential moderators (i.e. trait SR, and FNE; Hypothesis 3) were influencing the relationship between monitoring and young driver speed, additional hierarchical multiple regression analyses were employed.

**Randomisation to Groups**

Descriptive statistics for dependent and moderator variables suggested that randomisation to groups was successful (i.e. there were no notable differences between the groups at baseline, see Table 16 below). A series of one-way ANOVAs were then conducted and confirmed this empirically (see Table 17). As such, any differences to emerge between the groups at Time II were not due to pre-existing differences.

**Descriptive statistics**

Upon examination of the descriptive statistics (on untransformed variables), it appeared that there was a greater reduction in mean speed from Time I to Time II for those being monitored by the SDSS when driving (a mean reduction of 2.62km/h, SD = 4.19), as compared to those driving in the control condition (a mean reduction of 0.86km/h, SD = 6.64). Similarly, greater reductions in the number of speeding violations when comparing the Time I and II drives were observed for those driving with the SDSS (a mean reduction of 1.15) versus control group participants (a mean increase of .04). Such findings are in line with Hypotheses 1, although this remained to be confirmed via inferential statistics.

**Correlation analyses**

Pearson’s correlations (see Table 18) were examined in order to begin to conceptualise the relationships between the number of variables included in the current study, as well as to provide initial indications as to the likely influential moderator variables associated with outcome measures. First, of the four potential moderator variables (state SR, SRE [the self-report state SR measure], trait SR and FNE), none of these were found to be significantly correlated with any of the dependent variables. Significant correlations were only found between the FNE variable, and trait SR scores ($r = -.37$, $p = .02$), and the SRE
Table 17
Descriptive statistics for dependent and moderator variables across groups.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Control Group</th>
<th>Monitoring Group</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>Change TI - TII</td>
</tr>
<tr>
<td>Speed Time I</td>
<td>71.15 (7.32)</td>
<td>-</td>
</tr>
<tr>
<td>Speed Time II</td>
<td>70.29 (5.01)</td>
<td>-0.86 (6.64)</td>
</tr>
<tr>
<td>No. Violations Time I</td>
<td>1.91 (2.02)</td>
<td>-</td>
</tr>
<tr>
<td>No. Violations Time II</td>
<td>1.87 (1.79)</td>
<td>-.04 (1.52)</td>
</tr>
<tr>
<td>State SR</td>
<td>.06 (.05)</td>
<td>-</td>
</tr>
<tr>
<td>SRE</td>
<td>9.00 (1.48)</td>
<td>-</td>
</tr>
<tr>
<td>Trait SR</td>
<td>111.52 (18.11)</td>
<td>-</td>
</tr>
<tr>
<td>FNE</td>
<td>40.35 (9.51)</td>
<td>-</td>
</tr>
<tr>
<td>DBQ</td>
<td>14.17 (3.90)</td>
<td>-</td>
</tr>
</tbody>
</table>

Note: Speed Time I = mean speed during the baseline Time I drive; Speed Time II = mean speed during the experimental Time II drive; No. Violations Time I = the number of speeding violations recorded during the baseline Time I drive; No. Violations Time II = the number of speeding violations recorded during the experimental Time II drive; State SR = Stroop interference score; SRE = Self-report state SR score; Trait SR = Short Self-Regulation Questionnaire score; FNE = Brief Fear of Negative Evaluation score; DBQ = Driver Behaviour Questionnaire ‘Violations of Traffic Rules/Speeding’ subscale score.

Table 18
One-way ANOVA results across condition.

<table>
<thead>
<tr>
<th>Variable</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Time I</td>
<td>.59</td>
<td>.45</td>
</tr>
<tr>
<td>No. Violations Time I</td>
<td>.01</td>
<td>.92</td>
</tr>
<tr>
<td>Trait SR</td>
<td>.13</td>
<td>.72</td>
</tr>
<tr>
<td>FNE</td>
<td>1.03</td>
<td>.32</td>
</tr>
<tr>
<td>DBQ</td>
<td>.13</td>
<td>.72</td>
</tr>
</tbody>
</table>

Note: Speed Time I = mean speed during the baseline Time I drive; No. Violations Time I = the number of speeding violations recorded during the baseline Time I drive; Trait SR = Short Self-Regulation Questionnaire score; FNE = Brief Fear of Negative Evaluation score; DBQ = Driver Behaviour Questionnaire ‘Violations of Traffic Rules/Speeding’ subscale score.
variable reported a significant correlation with the number of RTCs the young driver had been involved in the past three years \((r = .36, p = .02)\). The moderator variables were further examined through hierarchical regression analyses at a later stage.

Speed and violations measures were found to correlate highly with each other, and across the two timepoints. Mean speed scores on the Time I baseline drive, for example, were found to correlate with Time II mean speed \((r = .61, p < .001)\), the number of speeding violations recorded at Time I \((r = .65, p < .001)\) and Time II \((r = .42, p = .004)\). Likewise, Time II mean speed scores correlated significantly with the number of speeding violations recorded at Time I \((r = .53, p < .001)\) and Time II \((r = .68, p < .001)\). Time I violations and Time II violations also correlated significantly \((r = .56, p < .001)\).

Driver history variables were also found to correlate with one another. The number of months that a participant had been driving while licensed positively correlated with the number of penalty points (i.e. the Irish system for recording driving offences) they had received for example \((r = .63, p < .001)\). Similarly, drivers who reported previously racing against another on a public road were more likely to report higher, riskier scores on the self-report ‘Violations of Traffic Rules/Speeding’ DBQ subscale \((r = .35, p = .02)\), and speeding violations at Time I \((r = .31, p = .02)\). In addition, the number of RTCs in the last three years reported by participants was found to correlate with the number of speeding violations recorded during the Time I baseline drive \((r = .31, p = .04)\).

**Mood, self-efficacy and motivation**

Measures of mood, self-efficacy and motivation were included to ensure that differences along these variables were not influencing SR-related outcomes. No significant differences in mood, or self-efficacy were reported between groups, or across the different timepoints following mixed factorial ANOVAs testing this. Motivation was measured post the Time II drive and Stroop task. No significant differences between the groups at first measurement were reported following a one-way ANOVA \((p = .07)\), or at the second timepoint \((p = .45)\). Across the two groups, motivation was seen to increase from the first to second timepoint, from \(M = 3.52 (SD = .86)\) to \(M = 4.05 (SD = .76)\) however. A mixed factorial ANOVA was conducted to examine whether these increases were statistically significant. A main effect of time, \(F(1, 40) = 11.91, p = .001\), partial \(\eta^2 = .09\), was identified, as was a significant interaction between condition and time, \(F(1, 40) = 5.49, p = .02\), partial \(\eta^2 = .02\). A series of post hoc, paired samples t-tests were then completed. The increase in
Table 19
Pearson’s correlations for dependent, moderator and demographic variable scores.

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Note: Mn Spd TI = mean speed during the Time I baseline drive; Mn SpdTII = mean speed during the Time II experimental drive; Viol TI = number of speeding violations during the Time I baseline drive; Viol TII = number of speeding violations during the Time II experimental drive; State SR = Stroop interference score; SRE = self-report state SR score; Trait SR = Short Self-Regulation Questionnaire score; FNE = Brief Fear of Negative Evaluation score; Mth Lic = number of months licensed; RTC No. = number of RTCs in the past three years; No. PP = number of penalty points in the past three years; Raced = Have you ever raced another driver on a public road (Yes/No); DBQ = Driver Behaviour Questionnaire ‘Violations of Traffic Rules/Speeding’ subscale score. * p < .05, ** p < .01, *** p < .001.
motivation scores within the control group was found to be significant, \( t(22) = -4.03, p = .001, d = -.85 \) (a large effect).

**Hypothesis Testing**

**Hypothesis 1.** Participants who were informed that their speed would be monitored by the SDSS will show significantly greater reductions in mean speed and speed violations (pre to post), than those in the control group.

Descriptive statistics provided initial support for this hypothesis (see Table 16 above). Across both groups, mean speed was seen to decrease from Time I to Time II from 70.38 km/h \((SD = 7.11)\) to 68.72 km/h \((SD = 5.05)\). The reduction in speed was most notable for the monitoring group however, who recorded a mean speed of 69.45 km/h \((SD = 6.92)\) at Time I, and 66.83 km/h \((SD = 4.53)\) at Time II, a reduction of 2.62 km/h \((SD = 4.19)\).

Similarly, notable reductions in the number of speeding violations from Time I to Time II were recorded for those in the monitoring group (from a mean of 1.89 \([SD = 1.79]\) violations, to .74 \([SD = 1.37]\)). Those in the control condition reported a marginal decrease from a mean number of 1.91 violations \((SD = 2.02)\) at Time I to 1.87 \((SD = 1.79)\) at Time II, a reduction of .04 \((SD = 1.52)\).

Mixed factorial ANOVAs were conducted to explore whether these were significant differences. Although results indicated no significant time, or group*time, effects for the mean speed variable, paired samples t-tests indicated that the monitoring group did significantly reduce their mean speed from Time I to Time II \((t[18] = 2.72, p = .01, d = .63)\), whereas the control group did not. With regard to the (transformed) speeding violations data, across the two groups, a main effect of time \((F[1, 40] = 7.22, p = .01, \text{partial } \eta^2 = .15)\) was observed, in addition to a significant interaction between time and condition \((F[1, 40] = 7.33, p = .01, \text{partial } \eta^2 = .16)\) (see Figure 18 below). A series of post hoc, paired samples t-tests were then conducted. In line with the hypothesis, significant differences were reported only for the monitoring group, \(t(18) = 3.26, p = .004, d = .75 \) (a large effect). Two, 2 (condition) x 2 (gender) between subjects ANCOVAs were also conducted, using the two TII speed-related outcome variables as DVs respectively, controlling for TI speed-related outcomes. No significant effect of gender was reported.
Hypothesis 2. **State SR will moderate the impact of SDSS condition on speed (mean speed and number of speeding violations).**

As described in Section C3.2.2, greater interference on the Stroop task would indicate that SR reserves were depleted during the Time II drive (i.e. this provides a measure of state SR during the Time II drive). This state SR variable was entered into a hierarchical, multiple regression equation, to see if the extent to which participants self-regulated during the Time II drive moderated SDSS monitor efficacy. Specifically, condition was contrast coded, the variable mean-centered (to reduce the potential impact of multicollinearity), and an interaction term (i.e. condition*mean-centered state SR moderator) was calculated. Two hierarchical multiple regression analyses were conducted. The first, examining mean speed, specified Time II speed as the DV, and Time I speed was entered as a control in Block 1. In Block 2, the contrast codes and mean-centered variable were included, followed by the interaction term entered in Block 3. This process was repeated taking the Time II number of speeding violations variable as the DV, and controlling for Time I violations in Block 1. No evidence of any interactions (i.e. moderation) emerged however, even when factors such as age, gender, months licensed etc. were also entered as statistical controls. Of note, a main effect of condition was recorded in Block 2 when running the moderation analyses using Time II mean speed ($B = -1.49, SE = .63, \beta = -.30, p = .02$), and the number of speeding violations ($B = -.18, SE = .06, \beta = -.35, p = .006$) as DVs, confirming the findings of the paired samples t-tests and mixed factorial ANOVA conducted to address Hypothesis 1.

*Figure 18.* Interaction between the (transformed) number of speeding violations and time, across condition.
This process was then repeated using the self-report SRE (i.e. self-report state SR) variable as a potential moderator. Once more, no evidence of moderation emerged, and main effects of condition were reported for both speed-related dependent variables.

**Hypothesis 3: Trait SR and FNE will moderate the impact of SDSS condition on speed.**

It was hypothesised that the trait SR, and FNE variables would also moderate the relationship between the implementation of SDSS monitoring and subsequent speed-related, behaviour change. As with the state SR variable, condition was contrast coded, scale variables were mean-centered and interaction terms (i.e. condition*mean centred moderator) were calculated. Again, two sets of hierarchical multiple regression analyses were conducted for each potential moderator variable, with mean speed, or mean number of speeding violations at Time II taken as the DV. Once more however, no evidence of any moderation emerged from the analyses, even when factors such as age, gender, months licensed etc. were also entered as statistical controls.

**C3.6 Discussion**

*Overview*

The primary goal of this study was to examine and measure young driver speed (both mean speed, and number of speeding violations) in response to driving with a monitoring SDSS. In doing so, it also sought to investigate the potential underlying theoretical mechanisms and moderators influencing any observed effects. Results suggest that the implementation of SDSS monitoring does reduce young driver speed, and decrease risk-taking. The theory of SR has also been identified as a likely underlying theoretical mechanism through which the SDSS monitoring process has its effect, however further investigation is warranted to confirm this. Contrary to hypotheses, no moderation effects of trait SR, or FNE were observed.

*Impact of SDSSs on young driver speed*

Specifically, while both groups exhibited a mean speed decrease across the Time I to Time II drives, this was found to be a significant reduction (reporting a medium effect size) for the monitoring group only. Likewise, overall speeding violation scores decreased across the baseline and experimental drives, however, this was a significant reduction (with a large effect size) solely for participants driving in the presence of the monitoring SDSS. These reported improvements are in line with the broader monitoring literature, much of which has
typically focused on monitoring improving various performance outcomes in the workplace (e.g. hand hygiene practices in hospitals, or quality of patient care, De Amici et al., 2000; Eckmanns, Bessert, Behnke, Gastmeier, & Ruden, 2006; Leonard, 2008; Mangione-Smith et al., 2002). They are also broadly in-keeping with reductions in speed recorded throughout the greater driver monitoring literature (e.g. Levick & Swanson, 2005; Toledo, Musicant, & Lotan, 2008), and the select numbers of young driver specific studies that have reported on driver speed as an outcome variable (e.g. Bolderdijk et al., 2010; Creaser et al., 2009; Farmer et al., 2010), although it must be noted that these studies do not typically focus on the provision of monitoring alone. The current findings also lend support to current young driver use of existing monitoring SDSSs available for use in the ROI (e.g. the DriveSave app).

The question remains however, as to whether these statistically significant findings translate to meaningful results in practice. Given that studies suggest that reductions of even 1km/h in mean speed may reduce the likelihood of a RTC occurring by 5%, and the severity of injury should one happen (Kloeden, Woolley, & McLean, 2004; Molin & Brookhuis, 2007; M. C. Taylor, Lynam, & Baruya, 2000) these findings would attest to the potential value of young driver SDSS use. It is also noteworthy that SDSS monitoring alone was provided in this study, suggesting that further improvements may be experienced once SDSS monitoring is combined with other mechanisms of change, such as feedback and/or financial incentives.

Self-regulation as a mechanism for change

Overall, evidence for SR as the underlying theory of change responsible for speed and violation decreases was not found in this study. It was anticipated that state SR (i.e. the extent to which the young driver self-regulated during the Time II drive) would moderate the efficacy of the SDSS in reducing mean speed and the number of speeding violations of participants. No evidence of this emerged however. This non-significant finding potentially reflects issues with the relatively small sample size recruited. It is also possible that driving with a monitoring app, and reducing speed to within legal limits (as the majority of young drivers regularly do) simply does not require as much SR as to cause significant depletion to be detected in a subsequent SR task. As such, more sensitive means of assessing state SR may need to be considered. Of note, examination of the open-ended motivation question following the Time II drive revealed that drivers in the monitoring group were more likely to explain their motivation during the Time II drive as due to ‘monitoring by app’, or because ‘I knew I was being monitored so I made more of an effort to stay within the speed limits and stay on the road’. Drivers in the control group typically reported reasons such as I ‘just drove
to get it done’, ‘finish the drive’, or ‘replicate how I usually drove’. Responses such as these would suggest that the theory of SR is of relevance here. Further investigation is needed however.

In order to advance on previous experiments, this study also included measures of mood, self-efficacy and motivation throughout to ensure these were not influencing SR and outcomes (Dang et al., 2013; Furley et al., 2013; Mayer & Gaschke, 1988). No significant differences in mood from task to task, or between groups were reported however, nor were any significant differences in self-efficacy. The control group reported a significant increase in motivation when completing the Stroop task, as compared to completing the Time II drive. Although their reported motivation following the Stroop task was not significantly different to the level reported by those in the monitoring group, the increase in motivation observed may have resulted in a better Stroop performance for those in the control group, potentially attributing in part to the non-significant findings in relation to state SR moderating SDSS efficacy.

Potential moderators of SDSS efficacy

There was no evidence of any of the specified moderating variables (trait SR or FNE) influencing SDSS induced behaviour change, even when variables such as age, gender or driving experience were statistically controlled for. From a theoretical perspective, this was unexpected. It is possible that when engaging with a more complex SDSS process (e.g. receiving monitoring and feedback, and/or financial incentives), and likely a greater extent of behaviour change, these relationships may be elucidated further. The consideration of other moderators (such as the extent to which young drivers accept the novel technology and are willing to drive with it) may also improve outcomes here. Last, although unexpected, in some ways this can be regarded as a positive finding, such that, at present, individual differences do not seem to play a role in SDSS monitoring efficacy. That is, SDSSs can be seen to function similarly across young drivers with varying individual difference characteristics.

Limitations

Simulator-based research was ethically necessary here, given that SDSSs have not been tested with young drivers before, and to ensure experimental control over the driving conditions experienced by participants, an improvement over previous studies. In addition, the drives were designed to emulate a typical Irish road within an Irish landscape, with Irish road markings and signs. Despite this however, these findings will need to be replicated on-road before definitive conclusions as to SDSS monitoring efficacy can be made. Whether the implementation of a monitoring SDSS would be sufficient in reducing young driver speed in
a complex traffic environment, or when a young driver is, for example, late for work, remains to be seen also. In addition, although the purpose of this study was to test the first drive of a young driver using a SDSS, future research must assess the extent of behaviour change over time, as this may vary longitudinally. Last, few SDSSs are provided or adopted by young drivers without feedback functionality or the potential for insurance discounts, and the optimal combination of these has yet to be revealed. In order to thoroughly evaluate SDSS use in a young driver context, a test of a more extensive system is needed.

C3.7 Contribution
This study marks the first, empirical test of SDSS monitoring efficacy within a young driver sample. For the first time, it has been demonstrated that implementation of a monitoring SDSS under laboratory conditions can significantly reduce mean speed and the number of speeding violations committed during young driver first use. It has also provided limited evidence that the theory of SR may underlie this effect. It has overcome the limitations of previous studies primarily by adopting a RCT design, using a validated driving simulator and controlled driving environment, and gender and age balanced sample. It advances on existing work by having incorporated assessments of the theoretical mechanisms influencing behaviour change in this context, and ensuring extraneous variables (such as mood, self-efficacy etc.) were not impacting on findings. This work can inform the greater driver monitoring literature, and lend support to the use of monitoring SDSSs by young, at-risk drivers. Most importantly, this study has built a foundation of evidence and protocol from which to base and test subsequent SDSS studies, including those that follow this chapter.

C3.8 Conclusions
Overall, the present findings were somewhat in line with the proposed hypotheses and the greater monitoring research literature. These suggest that SDSS monitoring alone has potential in reducing young driver speed-related risk-taking, upon commencement of driving with one of these. Given such results, it is also likely that when coupled with real-time alerts and/or financial incentives, SDSS use may have a similarly positive impact on young driver behaviour. Certain questions remain however, as to the optimal combination of more extensive SDSS features to maximise positive behaviour change, and the underlying theoretical mechanisms influencing such effects. Given the now established,
positive effects of engaging with a SDSS, further investigation of these applications is warranted.
Chapter 8 - Section C4: Examining the Impact of a SDSS that Provides Real-Time Visual Feedback Alerts and/or a Financial Incentive on Young Driver Speed.

C4.1 Abstract

**Background:** The findings of Study 5 indicated that SDSS monitoring can reduce young driver speed. Smartphone driver support systems typically offer functionality beyond monitoring alone however (e.g. they provide real-time feedback), and are often offered with a financial incentive for safe driving. The impact of such features has yet to be ascertained, as do the theoretical mechanisms underlying any of these potential effects, and whether individual difference variables may moderate them.

**Aims:** This study aimed to: 1) investigate the impact of an enhanced SDSS configuration on young driver speed in a simulated environment; 2) assess whether Self-Regulation (SR) and Operant Conditioning (OC) explain any changes that arise, and; 3) explore the potential moderating role of individual differences including trait SR, Fear of Negative Evaluation (FNE), acceptance and Delay Discounting (DD).

**Methodology:** Fifty-six young driver participants with full Irish driving licenses and current insurance completed a combined adaptation and 8km, SDSS-monitored, baseline drive (Time I). They were then randomly assigned to either drive 8km (Time II) with a SDSS providing real-time visual feedback on speeding violations (Group 1), a monitoring SDSS and the incentive to earn €2 for driving under the speed limit (Group 2), or with both feedback and an incentive (Group 3). Following both drives, participants completed a SR Stroop task measure, and last, a detailed participant questionnaire, recording demographic, driving history, and individual difference variables.

**Findings:** Main effects of time and condition emerged for the mean speed variable, with significant reductions at Time II reported for those in Group 2 and Group 3. Significant reductions in the number of speeding violations for those in Group 1 and Group 3 over time were also observed. There was no evidence of SR underlying these effects, however trait SR and FNE were found to moderate the impact of a SDSS financial incentive on mean speed.

**Conclusions:** The current findings suggest that a SDSS offered with a conditional financial inventive, or an incentive plus real-time visual feedback, significantly reduce young driver mean speed above monitoring alone. The provision of feedback, and an incentive plus feedback also resulted in reductions in speeding violations. Mechanisms of SR and OC likely
underlie this behaviour change process, however, further investigation is needed to ascertain this. Individual differences in responsivity to the implementation of a financial incentive among those low in SR, and high in FNE were also documented.

**Implications:** The use of a SDSS with a financial incentive, or incentive plus feedback is an optimal means to improve young driver risk-taking, although individual differences must be acknowledged here. The potential for driver distraction when engaging with real-time alerts must be investigated before definitive efficacy claims can be made however.

**C4.2 Introduction**

The central aim of this study was to examine the impact of real-time visual SDSS feedback alerts and/or a conditional financial incentive on young driver speed in a simulated environment. The study examined driver speed under three conditions: 1) Driving while in receipt of real-time visual SDSS feedback alerts; 2) Driving with a monitoring SDSS and a conditional financial incentive; and, 3) Driving while in receipt of combined real-time visual SDSS feedback alerts plus a conditional financial incentive.

The findings of Study 5 (Chapter 7) indicated that SDSS monitoring can be effective in reducing speed-related, risk-taking, and synthesised findings and conclusions drawn from the young driver monitoring efficacy research reviewed (see Study 3, Chapter 5) suggest that harnessing SDSS feedback and incentive-related mechanisms of change may improve speed-related outcomes. Such studies have typically used varying combinations of these however, to the extent that it is unclear which SDSS features (e.g. visual feedback alerts) or combined ‘packages’ (e.g. SDSSs that offer real-time feedback with an insurance incentive for safe driving, for example) are optimally effective. This has potentially contributed to the inconsistent efficacy findings reported across young driver monitoring studies (e.g. Bolderdijk et al., 2011; Farmer et al., 2010; Simons-Morton et al., 2013). Such studies have also largely focused on IVDR technology, failed to specify the underlying theoretical mechanisms influencing outcomes, and experienced methodological limitations.

In light of this, the current study sought to extend the current literature by testing the efficacy of a variety of SDSS components, and expand understanding of the psychological and theoretical mechanisms that can be harnessed by this novel technology to evoke young driver behaviour change.
C4.3 Rationale for the current study

Study 5 (Chapter 7) was a ‘proof of principle’ experiment, which indicated that SDSS monitoring alone can impact positively on young driver speed. However, SDSSs typically seek to influence behavior through more mechanisms than mere monitoring, and thus additional research is required to probe the efficacy of these. In particular, most systems are typically offered with some form of an incentive (e.g. a monetary reward) for adhering to specific driving parameters, and/or the device will provide real-time feedback while driving (auditory and/or visual alerts). These features draw from the broader, SR and learning (in particular, research relating to OC) research literature. Although these represent large, established bodies of research within the field of psychology, few studies have applied learning and SR theory to the study and evaluation of smartphone driver monitoring efficacy. This second SDSS experiment aimed to address this.

C4.3.1 Existing SDSSs. A variety of SDSSs are currently available for young driver download and use. These can be accessed from online app stores (e.g. the ‘iOnRoad’ app) for personal use, or from insurance companies, whereupon they are made available following the confirmation of a contract of use between both parties (e.g. the Irish ‘Drivesave’ app provided by Axa Insurance, or the ‘Go Drive’ app provided by 123 Insurance). The majority offer similar core features (e.g. the provision of in-vehicle feedback and post-journey reports), although the specific composition of these can vary from SDSS to SDSS. The iOnRoad app (whose features are depicted in Figure 19 below) for example, uses augmented reality to map drive progress in real-time and integrate alerts, whereas the TDSS in Creaser et al.’s (2009; 2011) research presents images (e.g. a red speed limit sign) as in-vehicle feedback when triggered over a set interface screen.

Common to a number of SDSSs currently available, is the provision of real-time and post-journey feedback, and the incorporation of some form of incentive for safe driving. These features can be understood to harness SR, where feedback provides objective evidence of personal progress to compare against ideal standards, and OC, when such feedback provides reinforcing praise, or negative reprimand, and incentives reinforce safe driving. The iOnRoad app for example, while not offered by a specific insurance company, can provide data to an insurer if the driver wishes to make this available, according to a contracted agreement. Users can then receive real-time feedback, post-journey reports, and, following a specified period of documented safe driving, an insurance discount to reinforce further safe driving behaviour. This resonates with much of the young driver IVDR research conducted to
Figure 19. Sample real-time and post-journey feedback provided by the iOnRoad SDSS.

date, wherein real-time feedback (as either audio, visual or audiovisual alerts) and incentives (typically financial, or social rewards, such as ranking amongst peers, or parental praise) have typically been the core psychological mechanisms of change employed and evaluated (e.g. Creaser et al., 2009; Farmer et al., 2010; Musicant & Lampel, 2010; Simons-Morton et al., 2013).

C4.3.2 Feedback and rewards for behaviour change. As detailed in Chapter 5, the provision and receipt of objective performance feedback to evoke positive behaviour change has long been studied within the field of psychology (e.g. see Alder, 2007; Hattie & Timperley, 2007; Hermansen et al., 2016 for review). Feedback has typically had a central role within a number of prominent theories of behaviour change (e.g. see B. Gardner, Whittington, McAteer, Eccles, & Michie, 2010a; Jamtvedt, Young, Kristoffersen, O’Brien, & Oxman, 2006; Webb, Sniehotta, & Michie, 2010), and in particular, is key to the SR process (Baumeister & Heatherton, 1996; Carver & Scheier, 1998; Vohs & Baumeister, 2011). Of relevance here, in recent years, the provision of smartphone-based monitoring and feedback
(often in conjunction with information or counseling) to promote health-specific behaviours (a research topic termed ‘Mobile’ or ‘M-Health’; Danaher, Brendryen, Seeley, Tyler, & Woolley, 2015; Lobelo et al., In Press), has seen a surge of interest, and success. Improvements in diverse behaviours, ranging from smoking cessation, to weight loss, to diabetes management have been reported using this approach (Fjeldsoe, Marshall, & Miller, 2009; Henry & Moore, In Press; Whittaker et al., 2009). Real-time, frequent feedback, with personalised, concise content, allowing for comparisons with others and delivered through an aesthetically pleasing, visual mode, has been identified as an optimal means to change health behaviour (Hermsen et al., 2016). These are understood to be particularly effective in the context of young adult or adolescent use (Dute, Bemelmans, & Breda, 2016).

Similarly, there is a large body of psychological literature on the positive impacts of providing rewards (or incentives) and punishments to improve human behaviour (Ben-Elia & Ettema, 2011; Li, Cox, Or, & Blandford, 2016; Medin, 2001; Schuitema, 2003). Operant conditioning research dates back to the early 1900s, and the seminal works of acclaimed psychologists Thorndike and Skinner (Medin, 2001). More recent study in the area of health behaviour change, or health risk reduction (relevant when considering fatality and injury outcomes as in the current driving context), has tended to focus on the provision of monetary rewards and financial incentives (some loss framed, relating to negative reinforcement) in motivating improvements (Kral, Bannon, & Moore, 2016; Mantzari et al., 2015; Paloyo, Reichert, Reuss-Borst, & Tauchmann, 2015; Tidey, 2012; Topp et al., 2013). Although mixed findings have been reported in the past, meta-analyses and systematic reviews conducted within the past 10-15 years indicate that the provision of monetary rewards can significantly increase the frequency of healthy behaviours (such as attendance for vaccinations, or increasing physical activity), and reduce dangerous ones (such as smoking) more than regular care, or no intervention (e.g. Kane et al., 2004; Purnell et al., 2014). Of note, more immediate reinforcement or punishment has typically been found to be most effective in successfully motivating behaviour change (Miltenberger, 2012).

**C4.3.3 SDSS Mechanisms of change.** The current programme of research proposes that improvements in young driver behaviour depend on objective feedback to support the development of skills and safe practices, and incentives for safe driving that effectively compete with the ‘thrills’ and enjoyment experienced when risk-taking (Cestac et al., 2011; Dogan et al., 2012). Previous young driver monitoring studies, and the findings of Study 5 (Chapter 7) suggest that SDSSs can be effective in evoking positive young driver behaviour change (e.g. Bolderdijk et al., 2011; Creaser et al., 2009), but the optimal features or
combinations of components of these interventions have yet to be empirically ascertained. Similarly, although positive findings regarding the implementation of driver feedback and financial incentives have been reported amongst older, or professional drivers in the broader driver monitoring literature, these too have typically lacked evaluations of the core components of this process, or sought to identify optimal monitoring conditions for behaviour change (e.g. Mazureck & Hattem, 2006; Merrikhpour et al., 2014). This is of particular importance within an Irish context as insurance companies continue to promote their SDSSs to young driver customers, despite gaps in the evidence that such SDSSs facilitate safe driving behaviours, or knowledge as to what SDSS package or combination of features has the greatest positive effect on driving behaviours. This study first examined the impact of receiving real-time, visual feedback alerts. Visual alerts were examined here, rather than audio feedback, as these are commonly employed by SDSSs (e.g. Creaser et al., 2009), and because young drivers have consistently reported annoyance with audio alerts (e.g. Creaser et al., 2009; 2011; McCartt et al., 2010; K. L. Young et al., 2003b), which may negatively impact upon acceptance and efficacy. This study also tested the provision of a conditional financial incentive, as this is a common SDSS feature offered by insurance companies recruiting young driver customers. The impact of engaging with a combined incentive and feedback providing SDSS was also examined, as a proposed optimal SDSS for young driver behaviour change, harnessing both SR and OC. These were all examined relative to a SDSS monitoring alone, baseline Time I drive in order to isolate the impact of the specific mechanisms being tested.

The efficacy studies reviewed within this thesis (see Study 3, Chapter 5), and the majority of broader driver monitoring research conducted to date (e.g. Horrey, Lesch, Dainoff, Robertson, & Noy, 2012; Levick & Swanson, 2005; Toledo & Lotan, 2008) have typically not examined the theoretical mechanisms underlying the efficacy of these conditions/features, or if individual differences could potentially moderate the impact of this technology. It is also not known if such findings will translate to SDSS use. As such, this study aimed to extend the literature by testing overall SDSS efficacy when providing real-time visual feedback alerts and/or a financial incentive, and also examine whether SR and OC underlie SDSS use. Although it was not possible to provide a direct test of OC in the current study (as learning due to reinforcement with financial incentives can only occur over time), findings in relation to the provision of real-time SDSS feedback to young drivers can provide an indication as to whether this has an impact. It also assessed the degree to which trait SR, and FNE potentially moderate the impact of the specified SDSS conditions on behaviour. In
addition, it incorporated delay discounting (Kirby et al., 1999) and acceptance of SDSS monitoring (as measured in Study 3, Chapter 4; Kervick et al, 2015) as potential moderator variables. Delay discounting was included here, as the extent to which an individual prefers immediate rewards (e.g. enjoyment from speeding) rather than any delayed financial incentives offered (such as the monetary rewards offered during the study), may moderate SDSS efficacy. Likewise, an individual’s acceptance of the idea and process of SDSS monitoring may also play a role in the efficacy of engaging with the different SDSSs offered on behaviour.

C4.3.3 Addressing methodological issues. This study also aimed to address a series of methodological limitations prevalent in the young driver, IVDR literature. First, isolated influences of real-time visual feedback alerts, and a financial incentive on young driver speed were assessed, and then compared with the influence of a combination of these (i.e. feedback + incentive), and a baseline monitored condition. Second, a driving simulator was employed to ensure all participants experienced identical driving conditions. The simulator is also a low-risk environment should the real-time SDSS feedback alerts distract the driver. As per Study 5, an equal gender distribution of fully licensed drivers aged between 18-24 years were recruited to ensure the entire, high-risk young driver demographic was incorporated. The short-term impact of SDSS engagement was assessed once more, with speeding-related outcomes taken as the primary variables of interest, due to the need to target this high-risk driving behaviour. Measures of psychological variables including mood, self-efficacy and motivation were also incorporated to ensure any reductions in mean speed or speeding violations were not due to these influencing SR (Furley et al., 2013). Last, a potentially more sensitive measure of state SR was used than in Study 5. Here, participants performed a Stroop task both pre and post the Time II drive. The difference in performance between the two tasks was then calculated, to provide a measure of depletion as a result of SR during the Time II drive (i.e. state SR).

To summarise, the current study employed a three-group experimental design that aimed to compare young driver speed (i.e. mean speed and speeding violations), between Group 1 (Feedback), Group 2 (Incentive) and Group 3 (Feedback + Incentive), over time (i.e. two timepoints, including a baseline and experimental drive). Specifically, with the aim of conceptually and methodologically advancing the existing literature, the following hypotheses were explored in the current study:
1. All participant groups (1-3) will show significant reductions in mean speed and speeding violations (pre to post), with Group 3 (feedback + incentive) demonstrating the greatest reductions relative to the others.

2. State SR will moderate the impact of SDSS condition on speed (mean speed and number of speeding violations).

3. Trait SR, FNE, acceptance and delay discounting will moderate the impact of SDSS condition on speed (mean speed and number of speeding violations).

C4.4 Method

Participants

The sample was recruited predominantly from students attending the NUI, Galway. Social media (e.g. Facebook and Twitter), email and on-campus poster campaigns were utilised to advertise the study to prospective participants in the Galway area. Participants were informed that they would be reimbursed with €10 for their and were randomly allocated to groups. All advertising materials informed the reader that only individuals with a full Irish driver’s licence, current insurance and smartphone, aged between 18-24 would be eligible to take part.

The final sample comprised of 56 participants, 28 male (50%) and 28 female (50%). A GPower analysis (Faul et al., 2007) indicated that a sample of 42 participants would be sufficient to identify any significant changes between groups, and over time, at α = .8, and an anticipated medium effect size. Mean participant age was 20.8 years (SD = 1.5 years) and participants had been fully licensed for an average of 2.4 years (SD = 1.52). A total of 55 of the young drivers identified as students (98%), with just one individual working full or part-time (2%). Thirty (54%) of the drivers personally owned their own car, with twenty-six (46%) driving vehicles belonging to their parents or partner. Four (7%) of the drivers had received penalty points in the past 3 years (for speeding, driving on a footpath, and proceeding beyond maximum design gross vehicle weight sign, where design gross vehicle weight exceeds maximum displayed), and 13 (23%) had been involved in a RTC. Six (11%) reported previously racing against another driver on a public road. All participants had normal or corrected to normal vision. Overall, 32% had last driven ‘earlier today’ (n = 18), 21% (n = 12) ‘yesterday’, 29% (n = 16) ‘during the last week’, 14% (n = 8) ‘during the last month’, and 4% ‘during the last year’ (n = 2).
Materials

Driving Simulator. Participants completed the drives of this study using the NUI Galway Carnetsoft driving simulator as described in Studies 4a + b (Chapter 6).

Simulated Drives. As per the findings of Study 4a, participants were required to complete a one-lap, adaptation drive prior to completing any experimental measures. Thus, three drives in total (i.e. adaptation, baseline Time I and experimental Time II) were completed by all participants as part of the current study. These drives were along the same, rural Irish track, featuring both curved and straight segments of roadway, no traffic, and a series of differing speed limits (60km/h, 80km/h and 100km/h) as in Study 5 (Chapter 7). The standard adaptation drive (8.89km) was first completed. Following this, participants were informed that their driving would be monitored by a SDSS and completed an 8km, Time I (baseline) drive which took approximately 8-10 minutes to complete. After this, they received their condition specific instructions and completed their final drive (experimental Time II), which was along an identical 8km track, again taking approximately 8-10 minutes to complete.

Smartphone Driver Support System. It was not feasible to design a functioning SDSS to operate with the novel driving simulator within the time constraints of the current programme of research. Instead, a black iPhone 4 ‘shell’ was used (i.e. the outer casing of an iPhone 4), within which an Arduino USB board had been inserted and fitted with a series of red LEDs behind the screen (see Figure 20 below). This was connected to the driving simulator via USB, and provided real-time visual speeding alerts when the driving simulator recorded a speeding violation (i.e. the LEDs lit up red). The phone screen remained blank when the driver was within the speed limit to denote safe driving. As during Study 5 (Chapter 7) the phone and connected cable was brought out from behind the simulator screens prior to the commencement of the Time I monitoring drive, and placed to the left of the centre screen, on the ‘dashboard’. The cable was then discreetly plugged into an electrical socket by the researcher and audibly vibrated, which the participant was informed, meant that it was ‘active’. No real-time visual feedback was provided during the initial Time I drive, and participants were informed that this drive was being monitored by the SDSS.
Dependent Variables - Speed Measures

*Mean speed and number of speeding violations.* Identical driving outcome variables were measured as those described in detail in Study 5 (Chapter 7). These were mean speed and the number of speeding violations recorded during each drive. As three separate drives were completed as part of the current study, mean speed and number of speeding violation scores were automatically generated and recorded by the simulator as output for each drive.

Dependent Variables - SR Measure

*Stroop Task - State SR.* The same Stroop task was completed by the participants as that described in Study 5 (Chapter 7), however, for this study, this was performed at two timepoints (pre and post the Time II experimental drive). The difference in performance (i.e. interference scores) between the two tasks was then calculated, to provide a measure of depletion as a result of SR during the Time II drive (i.e. state SR).

Moderator Variables

*The SSRQ – Trait SR, the FNE, acceptance and delay discounting.* Identical moderator variables as those described in Study 5 (Chapter 7), were measured during the current study. All reported good internal consistency, including the trait SR measure (the SSRQ; K. B. Carey et al., 2004; $\alpha = .91$), and the BFNE (Leary, 1983; $\alpha = .91$). The same acceptance measure used in Study 5 was also employed here as a potential moderator variable ($\alpha = .87$). Last, delay discounting was also measured, through the use of the 27-item Monetary Choice Questionnaire (MCQ; Kirby et al., 1999). As described in Study 4 (Chapter 4), for each item on this questionnaire, participants choose between a smaller, immediate amount of money, and a larger delayed amount (e.g. ‘Would you prefer €34 today, or €35 in
186 days?). Responses on the 27 items were grouped into three categories according to the magnitude of the delayed rewards (i.e. small, medium and large), and k-values, indexing the extent to which respondents chose smaller immediate amounts over larger delayed ones, were then determined for each monetary value and a geo-mean score obtained for the total delay discounting score.

**Additional Variables**

*The BMIS, self-efficacy, motivation and SRE.* Identical self-efficacy (Furley et al., 2013), motivation (Dang et al., 2013) and SRE (i.e. self-report state SR) variables (Furley et al., 2013) were administered as those described during Study 5 (Chapter 7). The SRE measure was administered twice, following both Stroop tasks, and a change score calculated to become the SRE score. A shorter, 4-item version of the BMIS was employed for the current study (Tyler & Burns, 2008), as compared to the 16-item measure recorded during Study 5. Good internal consistency scores (i.e. $\alpha > .70$) were recorded for all of these variables, across every timepoint (these were measured following the Time I and Time II drives, and Time I and Time II Stroop tasks, see Figure 21 below). The open-ended item asking participants to ‘describe their motivation’ after completion of the Time I and Time II simulated drives, and Stroop tasks was also included. A single, relaxation item (‘Following this break, how relaxed do you currently feel?’) was also responded to on a 7-item Likert scale (from 1 ‘Definitely not feel’ to 7, ‘Definitely feel’) following a 3.5 minute replenishing break, after the first Stroop task (Tyler & Burns, 2008), to ensure SR depletion did not impact on any subsequent experimental measures.

**Demographic Variables.** Identical survey items (see Appendix F) were administered to participants as during Study 5 (Chapter 7), including demographic items (e.g. age, gender etc.), a number of driving-related questions (e.g. ‘When did you last drive a car?’), the moderator variable questionnaires and the ‘Violations of Traffic Rules/Speeding’ DBQ subscale (Iversen, 2004, $\alpha = .80$).

**Procedure**

The experimental procedure is presented in brief in Figure 21 below. This is described in more detail in the following paragraphs. Participants were allocated an individual time slot to arrive at the driving simulator laboratory in the School of Psychology building, on the NUI Galway campus, and all were given €10 for taking part upon arrival. Once the consent form had been signed, the participants were brought beyond the room partition to the driving
simulator. They were given a standard, detailed introduction to the driving simulator, and were informed that their first drive (the adaptation drive) was merely for them to get used to driving the equipment. The drive itself was described in detail (e.g. a rural road, no other cars present, starting speed limit was 100km/h etc.), and they were instructed to drive as they normally would. Completion of this drive took approximately 10 minutes. The researcher left
the room during the drive, and participants were instructed to press a wireless doorbell once the drive had been completed to alert the researcher that the drive was over, and to re-enter the room.

Participants were then informed that for their next drive, they would be driving with a smartphone app that would monitor and record their speed on the phone. At this point the researcher placed the SDSS in front of the simulator. The drive itself was once again described in detail, and they were encouraged to drive as they normally would. Before beginning the drive, all participants filled in a 2-item measure of SDSS acceptance (e.g. ‘I want to use this app’) and 4-item BMIS scale. Immediately following the drive, participants were asked to take a seat at a nearby table to complete a ‘computer task’ (the Stroop task).

The Stroop task was briefly described with standard instructions, and prior to commencing this, participants completed a second BMIS, and a series of brief items to measure self-efficacy and motivation in relation to the Time I drive. Participants were instructed to start the Stroop practice trial and task as soon as they had finished the questionnaire.

After completing the Stroop task, participants were provided with a third mood questionnaire, and a series of measures assessing SRE (i.e. the self-report state SR measure), self-efficacy and motivation of the participant during the Stroop task. At this point, the participants were informed that they would be given a 3-4 minute break before continuing with the study. This was to replenish any depletion of the SR resource they may have experienced during the Stroop task before commencing the experimental drive. They were instructed to relax during this break, and that they would be provided with soothing background music (Gymnopédie No 1 by Erik Sartie) on the laptop to help them to do so (Tyler & Burns, 2008). The researcher left the room at this time, and returned after 3.5 minutes (the duration of the song). Participants were then asked to take a seat ‘behind the wheel’ for the third (final) drive, and were randomly assigned to either of three conditions.

For those assigned to Condition 1 (Group 1 - Feedback), these drivers were informed that they would again, be driving with the smartphone app that would monitor their speed. However, for this drive, they would receive real-time visual feedback on their speed, in which a blank app screen indicated that they were driving within the speed limit, and red lights indicated a speeding violation, whereby a speeding violation was defined as driving at a speed 10% greater than the current limit for more than five seconds. For those in Condition 2 (Group 2 - Incentive), these drivers were informed that they would be driving with a monitoring app, and that they could receive up to €2 by driving within the speed limit during
the drive. For every kilometre they drove without a speeding violation they would receive 25c (the drive was 8km in length), where, again, a speeding violation was defined as driving at a speed 10% greater than the current limit for more than five seconds. Last, those in Condition 3 (Group 3 - Incentive + Feedback), received the combined instructions of those in Condition 1 and 2 (i.e. they were informed that they would receive real-time feedback alerts, and could earn up to €2).

Another set of mood, motivation and self-efficacy measures were provided at this point, as was a single item relaxation measure (to provide an indication as to whether the replenishing break had been effective) before the Time II experimental drive began. The drive itself was identical to the previous in every way, except for the conditions described. Immediately after this, participants were asked to take a seat at a nearby table to complete a second ‘computer task’ (the Stroop task). The Stroop task was described with the same standard instructions as before, and participants also completed the same initial brief practice round before immediately commencing the task. Prior to beginning this, they completed mood, self-efficacy and motivation measures, and were instructed to start the Stroop task themselves as soon as they had finished the questionnaire.

Once they alerted the researcher that they were finished, they were provided with another mood questionnaire, and another SRE, self-efficacy and motivation measure regarding their experiences in completing the second Stroop task. The participants were then brought out to a desk set up in the corridor beside the simulator lab to complete a final questionnaire booklet. The questionnaire booklet comprised of demographic questions (e.g. age, gender etc.), driver behaviour items (the DBQ: Iversen, 2004), and potential moderating variables including the SSRQ, BFNE, and MCQ measures. Following this, the participants were debriefed orally, and asked to sign a retrospective consent form to signify their willingness for their data to be used in the study (including their adaptation drive data, which was, in fact, recorded). Those in the conditional financial incentive conditions (Groups 2 and 3) were then given €2, irrespective of their recorded speed violations. These participants were last asked to sign a receipt indicating that they had received this payment.
C4.5 Results

Data Analytic Strategy

Participant data were first examined to identify any missing values. None were observed, and so the distributions of participant scores were next screened and assessed for normality. The speeding violations data were found to be heavily skewed and kurtotic at both time points (e.g. Time II skew = 6.90, kurtosis = 49.65, $p < .001$), and for each participant group. These scores were relatively low (e.g. the majority of participants at Time II recorded zero speeding violations) to such an extent that an array of suitable transformations failed to satisfy normality criteria. As such, parametric statistics could not be availed of to examine these data. Mood was measured at five timepoints (prior to, and following, each task), and all demonstrated negative skew. Accordingly, these were subject to a logarithmic transformation, whereupon all met criteria for normality within and across groups. All the self-efficacy, motivation, state SR, SRE, trait SR, FNE, acceptance and delay discounting scores followed normal distributions within, and across the three groups.

To identify data trends, descriptive statistics (means and standard deviations) for the dependent and moderator variables were first calculated for each condition, and at each time point. To ensure successful randomisation to groups, a series of one-way ANOVAs were conducted to ensure there were no significant differences between the groups at baseline (Time 1). A correlation matrix was then prepared, to provide an initial indication as to the potential moderators for later analyses, and examine any other emerging relationships between the variables measured. A series of mixed factorial ANOVA analyses were also used to identify any differences in mood, self-efficacy and motivation between the three groups, across the different time points.

The main hypothesis (Hypothesis 1), that participants will demonstrate decreases in speed (both mean speed, and the number of speeding violations) following the implementation of their condition-specific SDSS, was tested using a mixed factorial ANOVA, using mean speed data as a DV, and McNemar’s tests, using speeding violations data as a DV, as the speeding violations data were not suitable for parametric analyses. Upon evidence of any significant effects stemming from the ANOVA analysis, these were further explored post hoc, with paired samples t-tests.

To assess whether SR was exerted during the Time II drive (Hypothesis 2), the calculated state SR score (indicating the extent to which SR was exerted during the Time II drive, relative to a Time I Stroop score) was examined as a potential moderator of SDSS
monitoring efficacy, and entered into a hierarchical, multiple regression equation. This solely used mean speed data as a DV, given the nature of the speeding violations data. This process was then repeated using the calculated SRE (i.e. self-report state SR) score. Last, to assess whether any other potential moderators (i.e. trait SR, FNE, acceptance and delay discounting; see Hypothesis 3) were influencing the relationship between monitoring and young driver speed, a further series of hierarchical multiple regression analyses were employed. Again, this solely used mean speed data as a DV, given the distribution of the speeding violations data.

Randomisation to groups

Successful randomisation to groups (i.e. no obvious baseline differences) was suggested by descriptive statistics for the Time I and moderator variables (see Table 19 below). A series of one-way ANOVAs then confirmed this (see Table 20). A non-parametric Kruskall-Wallis test also confirmed that no significant differences existed between the groups in terms of the number of speeding violations recorded during the Time I drive, $\chi^2 (2) = 2.40$, $p = .30$. Given these findings, any differences to emerge from the groups at Time II were understood to be due to the manipulations experienced during the experiment, and not pre-existing differences.

Descriptive statistics

Upon examination of the descriptive statistics, reductions in mean speed were observed for those in Group 2 (Incentive; reduction of 4.01 km/h) and Group 3 (Incentive + Feedback; reduction of 3.37 km/h) from Time I to Time II. Young drivers in Group 1 (Feedback) were seen to increase their mean speed slightly (+ 0.19 km/h) however. Decreases in the mean number of speeding violations across the two timepoints were reported for Group 1 (-2.68), Group 2 (-1.33) and Group 3 (-3.68). Of note, zero speeding violations were recorded during the Time II drives for participants in either of the incentive-related conditions (Group 2 and 3), whereas those in Group 3 reported a mean number of 0.74 ($SD = 2.31$) violations when driving with real-time visual SDSS feedback. Such findings suggest partial support for Hypothesis 1, although this remains to be confirmed with inferential statistics.
Table 20
Descriptive statistics for dependent and moderator variables across groups.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group 1: Feedback</th>
<th>Group 2: Incentive</th>
<th>Group 3: Feedback + Incentive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M (SD)</td>
<td>Change TI – TII</td>
<td>M (SD)</td>
</tr>
<tr>
<td>Speed TI</td>
<td>68.44 km/h (3.89)</td>
<td>-</td>
<td>66.60 km/h (3.66)</td>
</tr>
<tr>
<td>Speed TII</td>
<td>68.63 km/h (2.83)</td>
<td>.19 km/h (2.95)</td>
<td>62.95 km/h (3.75)</td>
</tr>
<tr>
<td>No Viol TI</td>
<td>3.42 (6.10)</td>
<td>1.33 (5.17)</td>
<td>3.68 (8.03)</td>
</tr>
<tr>
<td>No Viol TII</td>
<td>.74 (2.31)</td>
<td>-2.68 (5.87)</td>
<td>.00 (.00)</td>
</tr>
<tr>
<td>State SR</td>
<td>-.02 (.06)</td>
<td>-</td>
<td>.001 (.07)</td>
</tr>
<tr>
<td>SRE</td>
<td>-.74 (1.59)</td>
<td>-</td>
<td>-.17 (2.26)</td>
</tr>
<tr>
<td>Trait SR</td>
<td>119.79 (14.49)</td>
<td>-</td>
<td>114.39 (16.97)</td>
</tr>
<tr>
<td>FNE</td>
<td>34.84 (10.72)</td>
<td>-</td>
<td>30.67 (11.59)</td>
</tr>
<tr>
<td>Acpt</td>
<td>7.53 (1.81)</td>
<td>8.06 (1.80)</td>
<td>8.00 (1.73)</td>
</tr>
<tr>
<td>DD</td>
<td>-2.11 (.54)</td>
<td>-</td>
<td>-1.88 (.66)</td>
</tr>
<tr>
<td>DBQ</td>
<td>15.47 (4.91)</td>
<td>12.94 (5.23)</td>
<td>15.58 (3.53)</td>
</tr>
</tbody>
</table>

Note: Speed TI = speed during the baseline Time I drive; Speed TII = speed during the experimental Time II drive; No. Viol TI = the number of speeding violations recorded during the baseline Time I drive; No. Viol Time II = the number of speeding violations recorded during the experimental Time II drive; State SR = difference in Stroop interference scores across the two drives; SRE = self-report state SR score calculated across the two drives; Trait SR = Short Self-Regulation Questionnaire score; FNE = Brief Fear of Negative Evaluation score; Acpt = Acceptance score; DD = Delay Discounting score; DBQ = Driver Behaviour Questionnaire ‘Violations of Traffic Rules/Speeding’ subscale score.
Table 21
One-way ANOVA results across condition.

<table>
<thead>
<tr>
<th>Variable</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed Time I</td>
<td>1.38</td>
<td>.26</td>
</tr>
<tr>
<td>No. Violations Time I</td>
<td></td>
<td>.30</td>
</tr>
<tr>
<td>State SR Time I</td>
<td>.76</td>
<td>.47</td>
</tr>
<tr>
<td>SRE Time I</td>
<td>.12</td>
<td>.89</td>
</tr>
<tr>
<td>Trait SR</td>
<td>.65</td>
<td>.53</td>
</tr>
<tr>
<td>DD</td>
<td>1.92</td>
<td>.16</td>
</tr>
<tr>
<td>FNE</td>
<td>1.82</td>
<td>.17</td>
</tr>
<tr>
<td>Acpt</td>
<td>.50</td>
<td>.61</td>
</tr>
<tr>
<td>DBQ</td>
<td>1.98</td>
<td>.15</td>
</tr>
</tbody>
</table>

*Note:* Speed Time I = mean speed during the baseline Time I drive; No. Violations Time I = the number of speeding violations recorded during the baseline Time I drive; State SR Time I = the Stroop interference/depletion score following the Time I baseline drive; SRE Time I = self-report state SR score following the Stroop Time I; Trait SR = Short Self-Regulation Questionnaire score; DD = Delay Discounting scores; FNE = Brief Fear of Negative Evaluation score; Acpt = Acceptance score; DBQ = Driver Behaviour Questionnaire ‘Violations of Traffic Rules/Speeding’ subscale score.

**Correlation analyses**

Pearson’s correlations (Table 21) were examined to aid in initially conceptualising the relationships between the different variables incorporated in the current study. These were also assessed to provide potential indicators as to the likely influential moderators associated with the outcome measures. Of note, of the seven potential moderator variables, just two of these were found to significantly correlate with any of the outcome measures. The trait SR measure reported a correlation of $r = .27$ ($p = .04$) with Time II mean speed, and the SRE (self-report state SR) score recorded a correlation of $r = -.30$ ($p = .03$) with the Time II violations variable.

Driving simulator-related outcomes were observed to correlate highly with each other. Mean speed scores at Time I for example, correlated with the number of speeding violations recorded at this timepoint ($r = .64$, $p < .001$), and the mean speed scores at Time II ($r = .51$, $p < .001$). Likewise, the Time II mean speed score correlated with the number of speeding violations recorded during this drive ($r = .27$, $p = .046$).
Table 22
Pearson’s correlations for dependent, moderator and demographic variable scores.

<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
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<td>.06</td>
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</table>

Note: Mn Spd TI = mean speed during the Time I baseline drive; Mn SpdTII = mean speed during the Time II experimental drive; Viol TI = number of speeding violations during the Time I baseline drive; Viol TII = number of speeding violations during the Time II experimental drive; State SR = difference in Stroop interference scores across the two Stroop tasks; SRE = self-report state SR score, calculated across the two Stroop tasks; Trait SR = Short Self-Regulation Questionnaire score; FNE = Brief Fear of Negative Evaluation score; DD = Delay Discounting score; Accpt = Acceptance score; Mth Lic = Number of months licensed; RTC No. = number of RTCs in the past three years; No. PP = number of penalty points in the past three years; Raced = Have you ever raced another driver on a public road (Yes/No); DBQ = Driver Behaviour Questionnaire ‘Violations of Traffic Rules/Speeding’ subscale score. * = p < .05, ** = p < .01, *** p < .001.
Regarding driving history variables, a number of risky driving-related scores were found to correlate with one another. The number of RTCs a young driver had been involved in correlated significantly with the number of penalty points they had received in the past three years ($r = .37, p = .005$) for example. The number of RTCs variable was also found to correlate with the number of speeding violations recorded at Time II ($r = .27, p = .04$). Drivers who reported greater frequencies of racing against other drivers on public roads also self-reported higher (i.e. riskier) DBQ scores on the ‘Violations of Traffic Rules/Speeding subscale ($r = .35, p = .009$). Driver DBQ scores were also found to correlate negatively with trait SR scores ($r = -.28, p = .04$).

Significant correlations amongst potential moderator variables were also recorded, as were relationships between scores on these scales and a number of demographic variables. Trait SR and FNE reported a negative significant correlation ($r = -.34, p = .01$) for example, where higher trait SR was linked with lower FNE. Higher delay discounting was found to correlate with low FNE ($r = -.28, p = .03$) and higher State SR scores ($r = .32, p = .02$). Significant correlations were also noted between gender and scores on the trait SR ($r = -.31, p = .02$), and FNE variables ($r = .28, p = .04$), such that males reported higher SR and lower FNE scores than females.

*Mood, self-efficacy and motivation*

Measures of mood, self-efficacy and motivation were included to ensure that differences along these variables, across the different timepoints were not influencing outcomes. A series of mixed factorial ANOVAs were conducted to assess this. Main effects of time were reported for the mood, self-efficacy and motivation variables, however post hoc analyses revealed no significant differences between consecutive measures for each of these (that is, there were no significant differences along the mood, self-efficacy or motivation variables before, and after, a drive or Stroop task). As such, performance was not influenced by changes in mood, self-efficacy or motivation pre and post the drive/task.

*Relaxation*

Although not used for analysis purposes, it is worth noting that participants reported a mean score of 5.79 ($SD = 1.76$) on the relaxation measure following the replenishing three-minute break. The maximum score on this variable was seven, and no significant differences between groups were reported, $F(2, 54) = .26, p = .78$.
Acceptance

It is also noteworthy that the majority of participants agreed or strongly agreed (75%, \( n = 42 \)) that they would want to use this SDSS, and 69.6\% (\( n = 39 \)) agreed or strongly agreed that they intended to use a SDSS like this in future.

Hypothesis Testing

**Hypothesis 1.** All participant groups (1-3) will show significant reductions in mean speed and speeding violations (pre to post), with Group 3 (feedback + incentive) demonstrating the greatest reductions relative to the others.

Descriptive statistics for the mean speed TI and TII scores (see Table 20 above) indicated that, from the baseline Time I (monitored) drive, to the Time II experimental drive, mean speed decreased for those in Group 2 (Incentive; -4.01 km/h) and Group 3 (Incentive + Feedback; -3.37 km/h). A marginal increase in mean speed was reported for those participants in receipt of real-time visual alerts alone (Group 1; +.19 km/h).

In order to determine whether differences across groups were statistically significant, a 3 (group) x 2 (time) mixed factorial ANOVA was conducted. Mauchly’s test was not significant, and thus no sphericity corrections were employed. A main effect of time was reported, \( F(1, 53) = 18.23, p < .001, \text{partial } \eta^2 = .26 \), as was a significant interaction between time and condition, \( F(2, 53) = 5.41, p = .007, \text{partial } \eta^2 = .17 \) (see Figure 22).

**Figure 22.** Interaction between participant mean speed and time, across condition.
In order to examine these relationships more closely, a series of post hoc paired samples t-tests were conducted. A Bonferroni correction was applied to adjust for family-wise error rate, such that the adjusted criterion level was \( p = .017 \). Significant differences were found within Group 2 (Incentive), \( t(17) = 3.56, p = .002, d = .84 \), and within Group 3 (Incentive + Feedback), \( t(18) = 3.15, p = .006, d = .72 \). No significant difference was reported for Group 1 (Feedback, \( p = .79 \)). A 3 (condition) x 2 (gender) between subjects ANCOVA was also conducted, using mean speed at Time II as a DV, while controlling for TI. No significant effect of gender was reported.

As previously stated, the speeding violations data recorded at Time I and Time II was heavily skewed and kurtotic, such that transforming the data still did not result in a distribution that fell within the criteria for normality, rendering parametric analyses unsuitable. Descriptive statistics (see Table 19 above) demonstrated reductions in the number of speeding violations recorded for all three groups (Group 1 = -2.68, Group 2 = -1.33, Group 3 = -3.68). Notably, all drivers in Groups 2 and 3 recorded zero speeding violations during the Time II drive, as compared to those in Group 2, who reported a mean of 0.74 (SD = 2.31). McNemar’s tests were conducted, to determine whether the number of violators (i.e. participants who recorded at least one speeding violation) changed over time, within each separate group (see Table 22 below). A significant reduction in the proportion of violators and non-violators pre and post the SDSS intervention was only recorded for those in Group 3 (Feedback + Incentive), \( p = .03 \), and not for those in Group 1 (Incentive, \( p = .25 \)) or Group 2 (\( p = .45 \)).

Table 23

Number of violators and non-violators across group and time.

<table>
<thead>
<tr>
<th>Variables</th>
<th>Group 1: Feedback</th>
<th>Group 2: Incentive</th>
<th>Group 3: Feedback + Incentive</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Time I</td>
<td>Time II</td>
<td>Time I</td>
</tr>
<tr>
<td>Violators</td>
<td>7</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Non-violators</td>
<td>12</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

*Note:* Violators = number of participants who recorded at least one speeding violation; Non-violators = participants who recorded zero speeding violations.
A Wilcoxon-signed rank test was also conducted with Group 1 (feedback condition) data. This test was appropriate for use solely with Group 1 speeding violations data, as this group had suitable Time I and II scores (i.e., scores greater than zero) to conduct this rank test. It was reported that the number of speeding violations was significantly lower for those in Group 1 (Feedback) at Time II (\(Md_n = 0\)) as compared to Time I (\(Md_n = 0\); \(z = -2.14, p = .03, r = -.35\), a medium-large effect size) (Cohen, 1988).

**Hypothesis 2.** State SR will moderate the impact of SDSS condition on speed (mean speed and number of speeding violations).

As described in Section C4.2.3, state SR was calculated by subtracting the Stroop Time I interference score from the Time II data (creating a measure of the extent to which SR was exerted during the Time II drive, relative to a Time I Stroop interference score). This state SR variable was then entered into a hierarchical, multiple regression equation, to see if the extent to which participants self-regulated during the Time II drive moderated SDSS monitor efficacy. Specifically, condition was contrast coded using Helmert coding, wherein, for the first code, the feedback and incentive condition were compared (i.e., feedback was coded as -.5, incentive as +.5, and feedback + incentive as 0), and for the second, feedback + incentive was compared to the average of feedback, and incentive (i.e. feedback was coded as -.333, incentive was coded as -.333, and feedback + incentive was coded as +.667). This type of coding was adopted, as there was no control group to create a reference group (McGreal, Hyland, O'Hora, & Hogan, In Press). The state SR variable was then mean-centered, and two interaction terms (i.e., condition*mean-centered state SR moderator) were created. The speeding violations data were deemed unsuitable for use in a regression (due to floor effects with the Time II data). As such, first, the Time II speed was entered as the DV, and Time I speed was entered as a control in Block 1. In Block 2, the contrast codes and mean-centered variable were included, followed by the interaction terms entered in Block 3. No evidence of any interactions (i.e., moderation) emerged however, even when factors such as age, gender, months licensed etc. were also entered as statistical controls. Of note, a main effect of condition was recorded for both contrast codes \((B = -5.25, SE = 1.12, \beta = -.47, p < .001, \) and \(B = -2.27, SE = .96, \beta = -.23, p = .02\) respectively), in Block 2, confirming the findings of the paired samples t-tests and mixed factorial ANOVA conducted to address Hypothesis 1.

This process was then repeated using the SRE (self-report state SR) variable as a potential moderator. Once more, no evidence of moderation emerged, and main effects of condition were reported.
Hypothesis 3. Trait SR, FNE, acceptance and delay discounting will moderate the impact of SDSS condition on speed (mean speed and number of speeding violations).

It was anticipated that trait SR, FNE, acceptance, and delay discounting variables would potentially moderate the relationship between the condition specific SDSS, and subsequent speed-related behaviour change. A series of hierarchical multiple regression analyses were conducted to test for interactions between variables. As when testing for moderation by the state SR variable (above), condition was contrast coded using Helmert coding, and all potential moderators were mean-centered, to reduce the potential impact of multicollinearity. Interaction terms were then created for each prospective moderator. Following this, Time II speed was entered as the DV, and Time I speed was entered as a control in Block 1. In Block 2, the contrast codes and mean-centered variable were included, followed by the interaction terms entered in Block 3. No evidence of any interactions (i.e. moderation) emerged for the acceptance or delay discounting variables, even when factors such as age, gender, months licensed etc. were also entered as statistical controls.

With regards to the trait SR variable, and FNE, evidence of moderation was recorded for both of these measures. First, regarding trait SR (see Table 23 below), for Model 1, mean speed at Time 1 was entered as a control variable. Model 2 featured the addition of the contrast codes and mean-centered SR variable in Block 2, and Model 3 incorporated the addition of the two interaction terms in Block 3. There was a significant effect for condition (adjusted $R^2 = .51$, $F(4, 51) = 15.56, p < .001$), and evidence of a significant interaction between trait SR and condition (adjusted $R^2 = .58$, $F(6, 49) = 13.54, p < .001$). This was identified as between trait SR and the Feedback Vs Incentive term, ($B = .19, SE B = .07, \beta = .26, p = .005$). Similarly, regarding the FNE model (see Table 24 below), a significant effect for condition (adjusted $R^2 = .53$, $F(4, 51) = 16.23, p < .001$), and evidence of a significant interaction between the FNE variable and condition (adjusted $R^2 = .56$, $F (6, 49) = 2.81, p < .001$). This was identified as between FNE and the Feedback Vs Incentive term, ($B = -.22, SE B = .09, \beta = -.66, p = .03$). Upon inspection, the provision of a financial incentive was found to be associated with a decrease in speed amongst those lower in trait SR, but not amongst those scoring highly on the trait SR variable. The interaction between FNE and condition was such that the provision of an incentive was found to be associated with a decrease in speed amongst those higher in FNE, but not for those with lower scores on this variable.
Table 24
Summary of hierarchical regression analysis for trait SR model (n = 56).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Model 1</th>
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<th>Model 2</th>
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<th>Model 3</th>
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Note. Condition was represented as two dummy variables using Helmert coding; *$p < .05$, **$p < .01$, ***$p < .001$. 

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Table 25
Summary of hierarchical regression analysis for FNE model (n = 56).

<table>
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<tr>
<th>Variable</th>
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<td>Trait FNE</td>
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<td>Trait FNE x Feedback Vs Incentive</td>
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<tr>
<td>$F$ for change in $R^2$</td>
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*Note. Condition was represented as two dummy variables, using Helmert coding; *$p<.05$, **$p<.01$, ***$p<.001$.\*
C4.6 Discussion

Overview

The primary goal of this study was to examine young driver speed in response to driving with a SDSS that provided real-time visual feedback alerts (Group 1 - Feedback), a SDSS offered with a conditional financial incentive (Group 2 - Incentive), or a SDSS with a combined conditional financial incentive and real-time visual feedback alerts (Group 3 - Incentive + Feedback). It also aimed to identify the underlying theoretical mechanisms and any potential moderators influencing these effects. Results indicated that the implementation of a SDSS offered with a conditional financial incentive, or combination of a conditional financial incentive and real-time visual feedback alerts, significantly reduced young driver speed beyond monitoring alone (i.e. the baseline Time I drive). Limited statistical tests could be conducted on the speeding violations data, due to their non-normal distribution as a result of a floor effect during the Time II drive. Some evidence was provided however, that significant reductions in the number of speeding violations and number of young drivers committing speeding violations, could result due to engagement with SDSS feedback, or feedback combined with an incentive. Mechanisms of SR and OC likely underlie this behaviour change process, however, as with Study 5 (Chapter 8), conclusive findings were not found with regards to this. Last, evidence of moderation of SDSS efficacy by trait SR and FNE variables was established.

SDSS impact on young driver speed

Specifically, a significant decrease in mean speed was recorded for participants in Group 2 (Incentive) and Group 3 (Incentive + Feedback) across the two timepoints. Conversely, those in Group 1 (Feedback) were found to marginally increase their speed from Time I to Time II, although this was not significant. Similarly, although inferential statistics could not be used to examine the total speeding violations data, the number of speeding violations was observed to decrease across the two drives for those in Groups 2 and 3, to the extent that zero violations were recorded at Time II for both of these groups (although it could not be confirmed if this was a significant reduction or not). Of note, a significant decrease in the number of violations was reported for those in the feedback group (Group 1), although their mean number of violations at Time II was still .74 ($SD = 2.31$). The proportion of young drivers committing at least one speeding violation at Time I was also seen to decrease significantly at Time II for those in Group 3 (Feedback + Incentive).
Given young drivers’ heightened vulnerabilities to the negative impacts of driving at increased speeds (Geber, Baumann, & Klimmt, In Press; Møller & Haustein, 2014; Scott-Parker et al., 2013), that mean speed reductions, and total reductions in speeding violations were reported when a financial incentive, or combined SDSS feedback with a financial incentive was offered is a very positive finding, attesting to the potential value of more complex SDSS implementation for this driving group. Similarly, there is clearly a role for SDSSs providing real-time feedback alone in reducing speeding violations, although these alerts did not completely eradicate these. It also lends support to insurance companies and app designers currently providing SDSSs with similar features (e.g. a SDSS offered with a financial, insurance-related incentive) to young driver consumers.

In addition, these results are in line with previous research findings in this area. The positive findings regarding the financial incentive conditions (i.e. results from Groups 2 and 3), for example, reflect a number of young driver qualitative studies which have documented participants stating that they ‘wouldn’t mind obeying the rules making sure the system didn’t go off to be able to get lower insurance rates’ (Lerner et al., 2010, p. 30; K. L. Young et al., 2003b) for example. Such findings are also similar to the results of Bolderdijk et al.’s 2010 young driver monitoring study, which reported speed reductions when insurance-based, conditional financial incentives were offered to young drivers, although this was in addition to post-journey feedback. Two recent IVDR studies (published following the completion of this study) also attest to the validity of these findings. Mullen et al. (2015) conducted two, small-scale (n = 15, and n = 28) simulator studies with younger male drivers (< 30 years of age). Their first study reported that the provision of a combined token incentive (whereby tokens were earned for maintaining low speeds, and could be exchanged for gift vouchers) and real-time LED feedback alerts in a driving simulator significantly reduced mean speed and time spent driving above the speed limit during a 43km drive, as compared to control group participants. Their second study demonstrated that the provision of a token incentive alone, and combined token and real-time feedback showed the greatest reductions in speed, when compared to control and feedback only conditions during the same simulated drive, similar to findings reported here.

A young driver simulator study by Dijksterhuis et al. (2015) also reported similar findings. They found that young drivers (aged 18-25, n = 60) significantly reduced their speed and extreme maneuvers when provided with a financial incentive (drivers could earn up to €3 during experimental drives) and real-time audiovisual feedback via an iPod docked beside the driving simulator (n = 20), or a financial incentive plus post-journey reports
(obtained from an online webpage, \( n = 20 \)), as compared to a control group \((n = 20)\), and over time (two experimental drives, one week apart).

Findings from the broader monitoring literature also lend to the validity of these results, and in particular, the powerful role of financial incentives to promote safer driving, as compared to the provision of real-time feedback alone (e.g. see Reagan, Bliss, Van Houten, & Hilton, 2013; Toledo et al., 2008). So too does the greater psychological literature, where there is growing acknowledgement that conditional financial incentives are powerful motivators of behaviour change (Gaalema et al., In Press; Giles, Robalino, McColl, Sniehotta, & Adams, 2014; Mantzari et al., 2015). As previously described, these can be ascribed to conditional financial incentives and real-time feedback facilitating (and improving) goal-setting and commitment in a SR context. They can also promote learning through providing reinforcement and/or punishment to promote the occurrence of the desired behaviour (or cessation of undesirable ones), and positive, driving-related behaviour change, particularly over time.

That neither significant reductions in mean speed, nor comparable levels of speeding violation reductions were recorded for participants in Group 1 (Feedback) as compared to Groups 2 and 3, was somewhat unexpected. Although these results are in line with previous research (e.g. Mullen et al., 2015; Regan et al., 2013; Simons-Morton et al., 2013), SR and OC theory, and the findings of Study 5 (Section C.3), would suggest that the provision of real-time objective feedback in addition to monitoring should result in enhanced, positive behaviour change. Motivation to change is key here however, as, ultimately, if an individual is unconcerned about their objective performance in relation to ideal standards, instigation to change will not occur. In the absence of an incentive, or safety-related goal, young drivers may have been more motivated to complete the drive (and their study participation) as quickly as possible, rather than drive within the speed limits, or even drive more slowly for example. Some evidence for this was observed by the qualitative responses to the open-ended motivation question following the Time II drive. Participants in the two incentive-related groups typically wrote responses such as ‘The financial incentive motivated me to…keep down speed’ (Group 2) or ‘the added incentive of money was partly the cause… also I didn't want to see red lights on the smartphone’ (Group 3). Those in the feedback group however, frequently responded with statements such as ‘to do well’ or that they wanted to ‘go as fast as possible while keeping the phone screen blank’. Similar findings have been reported in the young driver IVDR study by Simons-Morton et al. (2013). Here, participants either received real-time visual LED alerts via a DriveCam monitor alone, or real-time feedback coupled
with post-journey feedback resources and progress reports sent to the young driver’s family. Significant improvements were recorded for those in the real-time and post-journey feedback group (termed ‘Lights Plus’ participants), but not for those who solely received real-time alerts and monitoring. Similarly, these findings were attributed to the fact that there were consequences associated with poor driving reports for those in the Lights Plus group, rather than those receiving real-time alerts alone, such that young drivers were motivated to avoid negative consequences, and earn positive rewards (such as parental praise) upon receipt of post-journey results.

Interestingly, a larger effect size was reported for those in receipt of a financial incentive alone, than those receiving a financial incentive combined with real-time SDSS alerts when considering mean speed reductions. This was contrary to hypotheses, which proposed that, in line with SR and OC theory, the combination of real-time feedback and a financial incentive would prompt greater speed and violations reductions. It is worth noting here that real-time alerts coupled with a financial incentive would likely amount to greater, long-term changes, as real-time alerts serve as prompts for young drivers as to their performance in relation to attaining the incentive. That is, in a short experimental drive with no distractions, drivers can moderate their driving with relative ease, and maintain lower speeds to ensure a monetary reward is received. However, should a young person drive for longer periods in the ‘real-world’, it is likely that driving performance could ‘drift’ over time if the incentive and threats to this were not salient. Real-time feedback would enhance the salience of such information and constitute a check against this drift.

When taking this short-term, mean speed finding for Group 3 however, and the findings in relation to the feedback only group (Group 1, i.e. no significant reductions in speed), these results could also be interpreted as pointing towards driver distraction. Higher cognitive load induced by attending to the SDSS alerts may have resulted in a certain amount of distraction from the driving task, such that speed limit signs were missed, or speed simply not attended to, to the same extent while traversing the track, resulting in slightly higher speed-related outcomes when compared to those in receipt of a financial incentive alone. Interestingly, previous studies have also suggested that when sufficiently motivated, driving-related performance can be prioritised and maintained, even in the presence of distractors (Shamsi, Yun-Cheng, & Eric, 2010; Wickens, Sandry, & Vidulich, 1983), which may account for the slightly poorer performance of those in Group 3 relative to Group 2 here, despite their overall improvements relative to those in Group 1. Conversely, there is also a body of research that suggests that when distracted, drivers may compensate for such
distraction by, amongst other behaviours, reducing their speed to better manage workload (Haigney, Taylor, & Westerman, 2000; Rakauskas, Gugerty, & Ward, 2004), potentially accounting for the speeding reductions observed for those in Group 3. Overall, it is not possible at present to determine whether SDSS engagement with real-time feedback alerts results in driver distraction, and whether driver distraction may account for some of the believed beneficial reductions in speed associated with SDSS use, or indeed, any non-significant findings. Clearly, the potential for young driver distraction must be explored further if a thorough evaluation of SDSSs is to be provided by the current programme of research.

It should also be noted however, that a number of drivers in the feedback group (Group 1) were observed to mention following their participation that they wanted to see how well the SDSS feedback worked (in the absence of any negative consequences for doing so), which may also account for their higher speed performance here. One Group 1 driver, for example, also recorded the following when responding to the open-ended motivation question: ‘I was pleased with the drive, I only broke the speed limit once, that was only because I tested to see if the app was actually working’. It is not clear how many drivers may have had similar experiences with the SDSS alerts, and whether this influenced the speed-related outcome variables measured for this group.

Mechanisms of change

With regards to SR theory, some limited evidence was recorded in support of this as one of the underlying theoretical mechanisms influencing SDSS-related behaviour change. First, in order to methodologically advance on the previous Study 5 (Chapter 8), and provide a more sensitive measure of state SR, Stroop performance was measured at two timepoints during the current study. No evidence was provided that this variable moderated SDSS efficacy however, and no evidence of the SRE self-report state SR variable doing so was recorded either. Again, this may reflect the likelihood that, as drivers are used to driving within the speed limit (e.g. only 16% of this sample self-reported breaking 120km/h speed limits ‘often’ or ‘very often’ for example), engaging with a relatively simple SDSS that encourages them to do so, may not require extensive self-regulatory resources such that depletion will occur. Of note, numerous studies purport that the more an individual practices SR, the easier they find it to regulate behaviour on future tasks (see Baumeister, 2014; Muraven, 2010). Participants completed a series of monitored drives and a SR Stroop task during the study, all of which may have helped them practice SR (in addition to their own experiences with driving regularly) by the time they came to take the final Stroop task. As
such this may have influenced the sensitivity of the state SR variable, resulting in the non-
significant moderation findings, however this is speculative at present.

That real-time feedback alerts significantly reduced the number of speeding violations
suggests that the violations constituted effective consequences to support OC. The majority
of speeding violators in this group reported just one speeding violation at Time II, suggesting
they may have received aversive feedback alerts for a single speeding violation, and then
reduced their speeding (i.e. positive punishment). Similarly, given the clear positive influence
of conditional financial incentives on young driver speed, and the described motivations of
the drivers during the experimental Time II Drive (e.g. ‘the added incentive of money was
partly the cause… also I didn't want to see red lights on the smartphone’) it is likely that
combined SR processes and OC underlie the efficacy of SDSSs. In terms of OC, the
improvements in driving behaviour here are likely established by means of rule-governed
behaviour, such that participants expected to receive a financial reward contingent upon their
safe driving behaviour (Cerutti, 1989). Furthermore, the real-time feedback alerts may
constitute a secondary negative reinforcer, established by the same instructions, as
participants sought to avoid the aversive stimulus which signified a potential financial cost.
The exact nature of these processes, however, is unclear and will remain so until reliable
measures are available for SR and OC.

Evidence of moderation by trait SR and FNE was recorded in this study. Specifically,
it was found that there was an interaction between condition and trait SR, whereby the
 provision of a financial incentive was associated with a decrease in speed amongst those
lower in trait SR, but not for those with higher trait SR. This makes intuitive sense, as, while
individuals with higher trait SR may not require external sources of reward to regulate their
behaviour, those with lower trait SR may need the promise of a reward to prompt and
maintain regulation of behaviour, such as a conditional financial incentive. As such, this
finding suggests that SR does play a role in SDSS efficacy, although this will need to be
replicated before definitive conclusions can be drawn. Regarding the interaction between
FNE and condition, this indicated that while the provision of a financial incentive may lead to
speed decreases for those high in FNE, they do not have a same impact on driver speed for
those lower in FNE. This can be attributed to those higher in FNE typically being concerned
with external monitoring, and particularly, a performance-related incentive, to the extent that
they are more inclined to change their behaviour when offered this, versus those scoring
lower on this variable (Friend & Gilbert, 1973; Lipton, Weeks, & De Los Reyes, 2016). Of
note, there was no evidence of either the acceptance or delay discounting variables
moderating the impact of SDSS condition here. That the delay discounting variable did not emerge as a significant moderator may potentially reflect the small scale of the delay to receiving the €2 reward. Even for those who prefer immediate rewards, a 10 minute drive may not be deemed as a substantial delay such that it would affect their decision-making. If assessing future longitudinal data however, wherein an insurance discount, for example, will only become available following a number of months, significant findings may emerge. With regards to the acceptance variable, the majority of young drivers reported high levels of SDSS acceptance overall, such that this potentially did not have much predictive value here. That individual differences may interact with the kind of SDSS offered to young driver consumers suggests that a screening process, wherein a young driver is offered a personalised SDSS package may prove optimal in evoking positive behaviour change going forward. Such findings need to be replicated before this kind of approach is adopted however.

Limitations

Although conducting this study in a driving simulator was ethically necessary given the novelty of SDSSs, and to ensure a higher level of experimental control over conditions, these findings will need to be replicated on-road and in more complex traffic environments, before any conclusive claims as to SDSS efficacy can be made. Similarly, although driving within the speed limit for ten minutes during a research study can be motivated by a financial incentive, the efficacy of SDSSs when a young driver is, for example, running late for work, or completing a long journey with peers remains to be seen. In-keeping with this, longitudinal research, including studies with incentives that more closely match an insurance discount (e.g. Bolderdijk et al., 2010), is essential here to provide more detailed results of SDSS impacts over time. The influence of engaging with more complex SDSS apps (e.g. those that facilitate social comparison with peer performance, or more extensive conditional alerts), and post-journey, or conditional real-time SDSS feedback also remains to be investigated, as a number of young driver IVDR studies have attested to the positive effects this type of feedback can have in conjunction with the features examined here (e.g. Farmer et al., 2010; Simons-Morton et al., 2013). Last, this study did not include a measure of driver distraction, which may potentially be influencing efficacy findings. This issue must be assessed if a thorough evaluation of SDSSs for young driver use is to be provided by the current programme of research.
C4.7 Contribution

This study is the first to demonstrate that the implementation of a SDSS with a conditional financial incentive, or an incentive in addition to real-time SDSS visual alerts, can significantly reduce young driver mean speed, and that incentives and/or real-time feedback can reduce speed violations when driving in a simulated environment. It has also provided limited evidence that the theories of SR and OC influence this process. By separately examining the influence of real-time feedback and/or incentives, and employing controlled driving conditions within a simulator, it has overcome limitations of previous studies, in addition to providing tests to ensure factors such as mood, or self-efficacy are not influencing findings. It has also identified and highlighted the need for investigation of driver distraction when engaging with real-time SDSS visual alerts. Such findings can inform the greater driver monitoring literature, and ultimately the work of insurers, SDSS providers and developers, and road safety bodies.

C4.8 Conclusions

Partial support was provided for the proposed hypotheses of the current study, and reported findings are in line with the consensus of the greater monitoring research literature. Drawing from these, such results suggest that SDSSs, particularly when used in conjunction with a form of conditional financial incentive (such as an insurance discount), can reduce young driver speed upon commencement of driving with this. From a theoretical standpoint, findings suggest that OC and SR mechanisms may underlie this effect, however this must be examined in further detail. Given that real-time alerts were not found to significantly influence young driver mean speed however, and the concerns voiced throughout the current programme of research, further examination of young driver distraction when engaging with in-vehicle feedback alerts is clearly warranted.
**Section C5: Interim Summary - SDSS Efficacy**

In considering the findings of Section C, the following points can be noted. First, in line with the conclusions of the efficacy systematic review, it has now been objectively demonstrated that SDSS usage can improve young driver speed, by significantly reducing their overall mean speed, and decreasing the number of speeding violations they commit when first driving with this novel technology. The provision of a SDSS with a financial incentive to avoid speeding violations proved the most effective means of reducing young driver speed here, with the provision of real-time feedback, and a combination of real-time feedback and an incentive resulting in significant speeding violation reductions. A SDSS providing monitoring alone also resulted in significant decreases along both speed-related variables (i.e. mean speed and number of speeding violations), although these were of a smaller magnitude. Such findings provide evidence and support for SDSS usage to be promoted as an innovative driving tool by insurers, and road safety bodies and organisations to reduce young driver RTC risk.

Questions do still remain as to the exact mechanisms underlying SDSS efficacy. No definitive evidence that SR influenced outcomes was reported throughout either of the two SDSS experiments, although young driver responses to open-ended motivation items suggested that this was the case, and trait SR emerged as a significant moderator of SDSS efficacy in the context of financial incentivisation. Improved measures of state SR going forward may be able to better inform this. That significant improvements (with medium and large effect sizes) were reported for SDSS conditions involving a monetary benefit for driving within the speed limit, and positive findings regarding the role of feedback in reducing speeding violations, were recorded, suggest that SDSS usage harnesses OC mechanisms, which can be examined in greater detail with longitudinal research. It is still unclear however, as to the magnitude of the reward needed to sustain safe driver speeds in more complex traffic environments, and on longer journeys. Similarly, the potential of certain moderator variables (particularly delay discounting) to influence SDSS efficacy in a longitudinal context must be elucidated. That individual difference variables may impact on SDSS usage, suggests that tailored SDSS packages may prove an optimal future approach, providing such findings can be replicated.

Last, the need to assess the potential for distraction when engaging with SDSS feedback emerged as a key consideration in this section. Distraction from an SDSS may influence efficacy, young driver RTC risk and also whether this technology is deemed
acceptable for adoption and use (K. L. Young et al., 2003b; Lerner et al., 2010). Section D commences an examination of this critical topic, in order to provide a thorough evaluation of SDSS use in a young driver context.
Section D - Distraction: Does engaging with real-time SDSS feedback result in young driver distraction?

Overview

This section seeks to begin the examination as to whether SDSS use can result in young driver distraction. To do so, it first presents a brief review of the scientific literature relating to distracted driving, with a focus on theory, and research examining distraction due to engaging with in-vehicle devices, in a young driver context (Section D.1). Building from this review, an initial empirical study designed to indicate whether the provision of real-time SDSS visual feedback can result in young driver distraction (as captured by a peripheral detection task and driving performance outcome measures) was conducted (Section D.2). Based on these preliminary findings on this topic, an interim summary of the potential for young driver SDSS distraction is then provided (Section D.3).
Chapter 9 - Section D1: Examining the Impact of Real-time Visual SDSS Feedback on Young Driver Distraction

D1.1 Abstract

**Background:** The findings of Study 6 indicated that driver distraction from visual SDSS feedback alerts may have influenced young driver speed throughout their experimental drive. Concerns also abound throughout the broader driving literature regarding the potential for young drivers to be distracted by in-vehicle technology such as SDSSs. This has yet to be empirically ascertained however.

**Aims:** This study aimed to provide a preliminary test of whether receiving real-time visual SDSS feedback could result in young driver distraction, as measured by performance on a Peripheral Detection Task (PDT).

**Methodology:** Fifty-one young driver participants completed an adaptation drive in the driving simulator, and a 1-minute PDT adaptation task, where they were required to press a response button as soon as they observed a PDT stimulus on-screen. Following this, they completed a 6km monitored baseline drive while completing a full PDT. All participants then completed a final 6km drive, in which they completed a PDT while receiving real-time visual feedback (a green light for driving within the speed limit, and red light for a violation) from a simulated SDSS.

**Findings:** Significant increases in reaction time on the PDT were recorded at Time II, as were increases in missed responses. No significant differences in lateral position scores were recorded throughout. Reductions in mean speed were recorded when young drivers received real-time SDSS feedback, as were decreases in the number of speeding violations.

**Conclusions:** Preliminary evidence suggests that real-time SDSS visual feedback can cause driver distraction as evidenced by impaired performance on a PDT when driving in the presence of this. Although mean speed and violation reductions were recorded when driving with SDSS feedback, these may be compensatory strategies due to distraction.

**Implications:** Further research is necessary to explore SDSS distraction in the context of young driver use before they can be recommended for widespread adoption and use.
D1.2 Introduction

Given the positive impact on young driver speed that SDSS implementation has been observed to have (Studies 5 and 6), but also the concerns voiced throughout Sections B and C regarding the potential for young driver distraction when engaging with in-vehicle technology alerts, this final empirical chapter sought to begin the task of examining the impact of engaging with an active, feedback-providing SDSS while driving. In the absence of SDSS-specific distraction research, this study first reviewed a body of literature on driver distraction, and then aimed to provide an initial examination of this complex topic by investigating whether receiving real-time visual SDSS feedback could potentially result in young driver distraction, as measured primarily by performance on a concurrent PDT and lateral position driving measures. The findings of this study provide a preliminary indication as to whether SDSS use could result in distracted driving, and can inform future investigations of this issue.

D1.2.1 Conceptualising driver distraction. Driver distraction has long been recognised as a substantial road safety issue. Concerns in the early 1900s, for example, were expressed that the introduction of windscreen wipers on a car could have a ‘hypnotic effect’ on drivers or otherwise distract them (Rouzikhah, King, & Rakotonirainy, 2013). Today, such concerns are typically expressed in relation to other sources of distraction, including the presence of children in cars, eating while driving, or the use of mobile phones while behind the wheel (e.g. Burns, 2014; H.-Y. W. Chen, Donmez, Hoekstra-Atwood, & Marulanda, 2016). One of the more prominent definitions of driver distraction was proposed by J. D. Lee, Regan and Young (2008), who describe it as ‘a diversion of attention away from activities critical for safe driving towards a competing activity’ (p. 7). Others have since made distinctions between visual, auditory, biomechanical and cognitive distractors (e.g. Rouzikhah et al., 2013; Victor, 2005).

Visual driver distraction, for example, occurs when, instead of focusing visual attention on the road ahead, the driver looks at another target, such as glancing at a real-time navigation system display (Kountouriotis & Merat, 2016). Distraction from auditory sources can take place when attention is focused on auditory stimuli, such as the radio or a passenger singing, rather than the sounds of the surrounding road environment (Brodsky & Slor, 2013; Ünal, Steg, & Epstude, 2012). Both can result in failure to detect safety relevant changes in the road conditions and surrounding traffic, reduced lateral control of the vehicle, and heightened RTC risk (Broström, Bengtsson, & Aust, 2016; Dibben & Williamson, 2007;
Biomechanical or physical distraction occurs when drivers manipulate an object/objects rather than maintaining their hands in the correct position on the steering wheel or gearstick etc. (K. L. Young & Regan, 2007). Reaching for food, or using a mobile phone while driving are common examples of this, and can result in delayed vehicular responses such as steering, braking or changing gears correctly and safely (Louveton, McCall, Koenig, Avanesov, & Engel, 2016; Rouzikah et al., 2013). Last, cognitive driver distraction is defined as any thoughts that may attract the driver’s attention such that they are no longer able to concentrate sufficiently on the driving task, and fail to drive safely (K. L. Young & Regan, 2007). Engaging in emotive conversation with a passenger, or via mobile phone can cause such distraction for example. This can result in reduced engagement in complex road scanning behaviours (decreasing capacity to anticipate and detect hazards), and negatively influence decision-making, such as selecting responses to successfully avoid hazards (e.g. swerving rather than braking in traffic; Cooper & Zheng, 2002; Kaber, Liang, Zhang, Rogers, & Gangakhedkar, 2012; Muhrer & Vollrath, 2011).

Despite these four forms of distraction being presented separately, it must be noted that these are not mutually exclusive (K. L. Young, Regan, & Hammer, 2003a). Texting while using a mobile phone, for example, may involve all four forms of distraction. Creating the message by pressing keys (or touching the screen if a smartphone; biomechanical and visual distraction), receiving text alerts (auditory) and focusing on the topic of conversation (cognitive), can all result in distracted, negative driving outcomes. In addition, it should be acknowledged that not all distractions influence driving, or driving outcomes, equally. Often, more experienced drivers, and those who may engage in a distracting behaviour (e.g. changing a radio station) more frequently, are more proficient at managing the increased workload associated with these tasks (K. L. Young & Regan, 2007).

D1.2.2 The dangers of driver distraction. Research clearly demonstrates that driver distraction can lead to RTCs and driver injury and fatalities. One of the best examples of this comes from the ‘100-Car Naturalistic Study’ conducted in the US, which tracked the behaviour of drivers in 100 vehicles over a period of approximately one year. Findings indicated that driver distraction was an influential factor in 23% of the documented crashes and near-crashes observed during this time (K. L. Young & Lenné, 2010) and further investigations based in the US have indicated that distracted drivers are 50% more likely to be seriously injured or killed in crashes, compared to attentive drivers (Ranney, 2008).

Statistics from the Australian National Crash In-depth Study (ANCIS) suggest that distraction is the second largest cause (25%) of crashes due to inattention (Beanland, Fitzharris, Young,
& Lenné, 2013a), with European sources reporting similar figures (European Commission, 2015). The RSA of Ireland have suggested that distraction is an influential factor in between 20-30% of RTCs each year (RSA, 2015).

Young drivers under the age of 25 have been identified as the most susceptible demographic driving group to distraction-related RTCs on a global scale (e.g. Buckley, Chapman, & Sheehan, 2014). The NHTSA report that drivers aged 20 years or under accounted for the greatest proportion of fatal RTCs (16%) deemed to be as a direct result of distraction in 2009 for example (Goodwin, O’Brien, & Foss, 2012). Distraction was also found to be a critical factor in 58% of RTCs involving young drivers aged 16-19 according to an analysis of video footage of over 1,000 moderate-severe RTCs, six seconds prior to their occurrence (Carney, McGehee, Harland, Weiss, & Raby, 2015). In addition, age has been found to moderate the relationship between the presence of in-vehicle distractions and the severity of RTC injuries sustained, such that worse outcomes are typically reported for younger distracted drivers (Ferguson, 2003; Lam, 2002). Similarly, in the Republic of Ireland, a large proportion of young drivers (>50% under the age of 25) have been found to frequently engage in distracted driving (e.g. mobile phone use while in transit), enhancing their likelihood of RTC involvement, as observed through their heightened RTC rates relative to other driving groups (Burns, 2014).

**D1.2.3 Distraction theory and young drivers.** The driving task is a highly complex process, understood to comprise over 1,600 different lower-level tasks (Walker, Stanton, & Young, 2001), in which a driver must, at a minimum, simultaneously control their vehicle, adjust their speed and trajectory, assess and deal with hazards, evaluate progress towards their driving goal, and make decisions regarding navigation. Multiple Resource Theory (MRT) is a psychological theory of human cognition which proposes that when people are challenged with completing concurrent tasks requiring the same resource channel (e.g. visually attending to the road ahead, while reading a text on a mobile phone), contention for limited resources is created, such that performance on one of the tasks (or both) may be impaired due to distraction (Horrey & Wickens, 2004; Wickens, 2002; 2008). This theory asserts that multiple, and parallel, processing channels exist at each stage of task processing, with each separate resource channel having limited capacity. Performance decrements are observed when demand for processing resources exceed the available supply within a single channel, when temporally overlapping tasks share a common response modality or stimulus.

Concurrent completion of two predominantly visual tasks, for example, can be predicted to induce greater performance decrements than completing visual and auditory
stimulus tasks at the same time. Interestingly, in dual-task settings, it has been demonstrated that shifting resources from one task to the concurrent other (both drawing from the same resource channel) can often improve performance on one task, at the expense of the other (Shamsi et al., 2010; Wickens et al., 1983), an effect that is magnified as task difficulty is increased. This theory has been successfully applied to the study of driver distraction on a multitude of occasions, and predicted poorer, distracted driving outcomes with regards to visual distraction (i.e. driving while engaging in a secondary visual task), for example, or cognitive distraction (e.g. Liang, 2009; Liang & Lee, 2010; Louw, Zschernack, & Gobel, 2013; Y. Zhang, 2011; K. L. Young & Regan, 2007).

This theory provides a useful explanatory framework through which to understand young driver distraction. As previously outlined, the driving task is a notably complex process, requiring extensive attentional resources and effort to conduct the series of necessary physical manoeuvres to operate the vehicle safely alone. The driving process becomes automatic over time, with practice/training however, such that the all-encompassing task of driving requires substantially less resources as driving experience increases (Freydier, Paxion, Berthelon, & Bastien-Toniazzo, 2013; J. D. Lee, 2007; Paxion, Galy, & Berthelon, 2014). This leaves greater attentional resources available for use during any potential secondary, or additional multiple tasks to driving (e.g. changing a radio station, making a hands-free phone call etc.). With regards to younger, more inexperienced drivers (for whom this process is not yet automatic), the driving task is still distinctly effortful however, requiring substantially more resources. Thus, in line with MRT, they are more likely to experience greater distraction (or ‘interference’) than older, more experienced drivers, due to the fact that their resource pools from which they draw while driving reach capacity sooner, such that there is less available to cope with any additional task demands. That is, their engagement in any additional tasks to driving may result in more extensive performance degradation in one or both of these as driving requires greater resources for them than for more experienced drivers. This has been consistently observed in young driver dual-task experimental research. Reduced young driver scanning of the roadway, and more harsh, delayed braking occurrences due to cognitive distraction has been recorded, for example (Harbluk, Noy, & Eizenman, 2002). Likewise, distraction due to phone use while driving has resulted in greater young driver harsh braking, impaired reaction times in hazard perception (Haque & Washington, 2015), and reduced control of the vehicle and deterioration in car-following (Saifuzzaman, Haque, Zheng, & Washington, 2015).
It should be noted that young drivers are also simply more likely to engage in distracting behaviours (e.g. engaging with peer passengers while driving, using a mobile phone to update social media etc.) than other driving groups, due to erroneous optimism biases as to their capabilities to manage driving demands (e.g. see Westlake & Boyle, 2012; White et al., 2011). Moreover, if they divert resources to secondary tasks coupled with impairment due to alcohol/drug use or fatigue, driving outcomes may be even more severe (Bingham, Shope, & Zhu, 2008; Ferguson, 2003; Simons-Morton, Guo, Klauer, Ehsani, & Pradhan, 2014).

**D1.2.4 In-vehicle technology and distraction research.** Recent advances in, and increased demand for, in-vehicle infotainment technologies (e.g. satnavs, eco-driving systems etc.) have generated a competitive market in which manufacturers of wireless devices, applications, computers and automobiles are releasing novel products at a rapid pace, without testing such technologies to previous standards (Leveson, 2011). Likewise, scientific research and legislation on use has had to ‘play catch-up’ as novel technologies are brought to market without established safety parameters (Parnell, Stanton, & Plant, 2016). A small number of studies from the broader driver IVDR literature have assessed driver monitors and distraction. Overall, the findings from such studies have been relatively mixed, with some reporting little to no evidence of distraction and improvements in driving performance (e.g. slower speeds) when in receipt of real-time in-vehicle feedback alerts (e.g. Birrell & Young, 2011), whereas others have reported reduced visual scanning and poorer driving outcomes (Hallihan, Mayer, Caird, & Milloy, 2011; Martens & van Winsum, 2000), or self-report distraction (Stillwater & Kurani, 2013).

A study by Birrell, Stewart and Young (2011), for example, examined the impact of engaging with real-time visual feedback provided by their in-vehicle FootLite eco-driving system. They conducted a repeated measures, 25-participant study in a high fidelity driving simulator, and employed a secondary visual PDT to infer driver distraction. Such tasks are common, established means of objectively assessing workload during driving, and have been demonstrated to be sensitive to changes in workload and distraction while engaging with in-vehicle information systems (Harms & Patten, 2003; Jahn, Oehme, Krems, & Gelau, 2005). Their basic premise is that during periods of increased workload, drivers will reduce the time spent scanning the peripheries of their vision, and perform more poorly in detecting peripheral stimuli, demonstrating their distraction from the driving task. Birrell et al. found that drivers in receipt of feedback alerts reported significant decreases in mean speed and time spent speeding, excessive acceleration and deceleration. Moreover, there was no
evidence that these reductions were due to compensation for distraction or cognitive overload, as their PDT performance actually improved in the presence of feedback alerts. There were also no delays in total journey time reported or increases in headway, suggesting that any reductions observed were simply in line with the eco and safety recommendations of the FootLite device. In addition no significant increases in the Driver Activity Load Index (DALI; Pauzie, 2008), self-reported for each participant, were recorded.

Similarly, a high fidelity simulator study was conducted by Rouzikah et al. (2013) to examine the impact of receiving eco-driving feedback on driver distraction using a PDT, and compare the impact of this to engaging with a navigation device or a CD changing task. It is relevant to note that in this case, the visual eco-driving feedback was provided via short messages displayed on a Personal Digital Assistant (PDA) mounted on the simulator dashboard, similar to a SDSS. Twenty-two participants were recruited, and all completed a baseline drive, visual eco-feedback drive, CD-changing drive and a final drive while using and entering information into a navigation system. This process was then repeated on a second day, to assess practice effects, and examine whether this could mitigate distraction. They reported that, in terms of self-report workload (the DALI measure), engaging with eco-driving feedback did not significantly increase this, although changing a CD or entering a destination into a navigation device did. Similarly, there was no significant difference between baseline and eco-driving measures in terms of missed responses on the PDT, although these were reported for the other two conditions. They also reported evidence of a practice effect, wherein participants recorded significantly less missed responses on the PDT second day when driving with the eco-driving feedback. This was also reported for the navigation and CD changing conditions. Last, they split the sample according to age, and found no differences in results for either 18-24 year old drivers \((n = 6)\), versus those aged 25-66 years \((n = 16)\) (these analyses had notably low power however). Overall, they concluded that workload does increase when engaging with eco-driving feedback, although it does not do so significantly. In addition, this was found to be less cognitively demanding than either of the two other ‘everyday’ driving scenarios, in line with Birrell et al.’s findings.

Neither of these studies was without limitations however. Both used small sample sizes, predominantly older, experienced drivers, and relatively simple traffic environments, for example, and other research studies have reported findings contrary to this. A simulator study \((n = 54)\) conducted by Martens and van Winsum (2000) assessed engaging with feedback provided by an in-vehicle information system while completing a PDT and drive, during which a series of critical events (e.g. a lead vehicle braking suddenly etc.) occurred.
Engaging with audio feedback was found to result in greater distraction, as evidenced by slower reaction times and fewer correct responses on the PDT during the drive as compared to a baseline drive segment, suggesting that fewer attentional resources were available due to engaging with the feedback system. Likewise, a study by Stillwater & Kurani (2013) reported qualitative data following driver exposure to an eco-driving feedback device in relation to distraction. Forty-six individuals drove with an experimental vehicle equipped with an eco-driving interface for one month, with the feedback device activated for the final two weeks. Although many favourable descriptions of the technology were provided by the participants during the semi-structured interviews, many of them expressed that they had felt distracted by the presence of the eco-driving device in the car, e.g. “It was just distracting, and then it’s like, what, every tenth of a mile how much was I getting and it goes up and down and up and down and it changes colours. It changes colours. I’m going… I’m doing something wrong, and it – you know, it’s just not something I felt was comfortable” (p. 94).

Four young driver monitoring studies have reported on (limited) indicators of distraction when engaging with in-vehicle monitoring devices and real-time feedback alerts. First, the 2009 TDSS study conducted by Creaser et al. included a brief self-report measure of the level of effort involved in attending and adhering to SDSS alerts while driving. This measure was the Rating Scale of Mental Effort (RSME; Ziljstra, 1993) and was completed immediately following an eight-mile test drive with an experimenter present. The 16, young driver participants rated the mean level of workload associated with driving with their prototype SDSS as 23.2 (SD = 10.6), corresponding to a low level of workload, classed as ‘a little effort’. During their 2011 TDSS study, Creaser and colleagues again administered the RSME scale to the recruited teen drivers, which they completed following a regular and then TDSS monitored test drive. They rated driving without the TDSS as ‘a little effort (M = 27.87, SD = 16.18), but driving with the TDSS as ‘some effort’ (M = 34.90, SD = 22.79). This was found to be a significant increase, t(29) = -2.12, p < .05. For reference, the maximum value on this scale is 150, and a score of 110 is considered ‘extreme effort’. As teen drivers were experiencing the TDSS for the first time, reporting that the system required some effort was deemed a reasonable expectation. Indeed, the researchers remarked in their report that they anticipated that teen drivers would soon become accustomed to driving with the TDSS, and the mental resources required to interact with it would become lower as they gained more experience with the system. A study by McCartt et al. (2010) included a one-item measure of distraction following young driver use of an IVDR. This enquired ‘Did alerts ever distract you from driving safely?’ Twenty-seven percent of teen drivers who received
both real-time alerts and immediate parental notifications sent on engagement in a specified risky driving behaviour reported that ‘yes’, the alerts distracted them. Thirty-five percent of those in a group who received conditional real-time alerts (i.e. they had a brief time window following a real-time alert to improve their driving or a parental notification would be sent) reported distraction. Similarly, monitoring research by Dijksterhuis et al. (2015) reported no significant differences across real-time audiovisual feedback versus control group participants along a seven-point, single distraction item: ‘In general, to what extent did you feel distracted during this drive?’. Scores ranged from 2 - 3.5 on this variable (where a score of seven denoted maximum distraction).

D1.3 Rationale for the current study

The greater driving research literature has attested to the dangerous effects of distraction on driving and safety-related outcomes (Beanland et al., 2013a; Klauer, Dingus, Neale, Sudweeks, & Ramsey, 2006; K. L. Young & Lenné, 2010; K. L. Young & Salmon, 2012). This is particularly the case for young, inexperienced drivers, for whom the driving task is not yet automatic, requiring greater attentional resources such that dealing with any additional distractors may result in more negative outcomes (Freydier et al., 2014; Guinosso, Johnson, Schultheis, Graefe, & Bishai, 2016; J. D. Lee, 2007). Limited research suggests that young drivers may experience increased workload in the presence of smartphone based and IVDR real-time feedback (e.g. Creaser et al., 2009; 2011; McCartt et al., 2010). As such, the potential for SDSSs to cause distraction when used by vulnerable young drivers must be assessed if a thorough evaluation of this technology is to be provided, as is the aim of the current programme of research.

This study sought to address existing conceptual gaps in the driver monitoring and distraction literature. The vast majority of young driver monitoring studies have simply not considered the potential negative impacts that engaging with real-time feedback may have, nor provided any objective measures to estimate such effects. In particular, MRT would suggest that visual feedback alerts stand to cause young driver distraction while driving, due to the predominantly visual nature of the driving task and their limited attentional reserves (Liang, 2009; Wickens, 2008; K. L. Young & Regan, 2007). In addition, the current study considered the possibility that the effects of real-time feedback, such as reductions in driving speed may be due to compensatory behaviours resulting from cognitive overload and distraction (Birrell & Young, 2011), rather than protective feedback. Finally, it is noteworthy
that, amongst the broader driver monitoring literature, no consensus as to whether engaging with real-time feedback distracts older drivers has been reached. If older, more experienced, drivers experience distraction when engaging with real-time alerts, such distraction will likely be an issue for young drivers, and needs to be addressed.

In aiming to address previous methodological issues within the research literature, this study employed a larger, more representative young driver sample. It incorporated approximately equal numbers of male and female participants (M = 25, F = 26), with an age range of 18-24 years to ensure representation across the target, high-risk driving demographic. In addition, this study aimed to infer and empirically assess distraction via objective measures of performance on an established PDT (Martens & Van Winsum, 2000), as well as outcome measures provided by the driving simulator (i.e. lateral position-related scores to indicate vehicle control), as opposed to the use of (potentially biased) self-reports. In conjunction with this, speed-related variables (mean speed and number of speeding violations) were also recorded, to ascertain whether any behavioural changes observed (e.g. a mean speed reduction) due to the feedback alerts provided could be attributed to compensation due to distraction. As with the previous empirical studies in this programme of research, this study was designed to assess the short-term, immediate impact of driving with a novel SDSS for licensed young drivers.

In summary, the current study employed a repeated measures design that aimed to compare young driver PDT performance when driving ‘as normal’ with an inactive SDSS, versus driving in the presence of a SDSS providing real-time visual feedback while driving in a simulator. Scores on the PDT, in conjunction with lateral position driving outcomes (i.e. vehicle control) were measured to provide objective indicators of young driver distraction, and speed-related variables (mean speed scores, and number of speeding violations) were included to provide insight into the potential issue of compensatory distracted driving behaviours, and SDSS feedback efficacy. Specifically, with the aim of conceptually and methodologically advancing the current literature, the following hypotheses were explored:

1. Participants will perform worse (i.e. slower response times, and more missed stimuli) on the PDT when in receipt of real-time visual feedback from the SDSS, than during their baseline drive.
2. Participants will demonstrate reduced control over their vehicle (i.e. higher standard deviation of lateral position [SDLP] and RMDLP scores) when in receipt of real-time visual feedback from the SDSS, than during their baseline drive.
3. Participants will reduce their mean speed and number of violations when in receipt of real-time visual feedback from the SDSS, as compared to baseline driving, in conjunction with reduced PDT performance and lateral control to indicate compensatory behaviours.

**D1.4 Method**

*Participants*

The sample was recruited predominately from a 2nd year Social Psychology module within NUI Galway. Course credit was provided to those who completed the experiment as part of the module, and others were reimbursed with €10 for their time. The total sample comprised of 51 participants, 26 male (51%) and 25 female (49%). A GPower analysis (Faul et al., 2007) indicated that a sample of 34 participants would be sufficient to identify any significant changes over time, at $\alpha = .8$, and an anticipated medium effect size. Mean participant age was 20.53 years ($SD = 1.55$) and participants had been fully licensed for an average of 2.2 years ($SD = 1.38$ years). A total of 49 of the young drivers identified as students (96%), with two at full or part-time work (4%). Twenty-seven (53%) of the drivers personally owned their own car, with 24 (47%) driving vehicles belonging to their parents or siblings. Six (12%) of the drivers had received penalty points in the past 3 years, all of which were for speeding, and eight (16%) reported previously racing against another driver on a public road. All participants had normal or corrected to normal vision. Overall, 31% ($n = 16$) had last driven ‘earlier today’, 18% ($n = 9$) had driven ‘yesterday’, 29% ($n = 15$) had driven within the ‘last week’, 10% ($n = 5$) within the ‘last month’ ($n = 4$), 8% ($n = 4$) during the ‘last year’, and 4% ($n = 2$) ‘more than one year ago’.

*Materials*

**Driving Simulator.** Participants completed the drives of this study using the NUI Galway Carnetsoft driving simulator described in detail in Studies 4a + 4b.

**Simulated Drives.** Participants completed Study 5 (Chapter 7) prior to completing the current study (i.e. both were completed during the same testing session, using the same participant sample). Thus, they had completed a one-lap adaptation drive, baseline and experimental (i.e. SDSS monitored or not) drive prior to undertaking the series of distraction experiment drives.

Three drives were completed during the distraction component of the study. These drives featured the same Irish rural road track as described in Studies 4, 5 and 6 (i.e. straight
and curved segments, no other cars present, starting speed limit of 100km/h etc.), however this track featured twice as many speed limits as the usual rural road track, to create more opportunity for young drivers to interact with the real-time SDSS feedback during the Time II drive. Participants first completed a one-minute, standard practice PDT (see the ‘dependent measures’ section below) drive, where they drove for one minute along the track while responding to the PDT stimuli presented on the screen. Next, they completed the baseline (Time I) drive, which involved driving a 6km distance on the same rural road track, responding to the PDT stimuli, while driving with a simulated SDSS that provided no feedback (see Figure 23 below). Last, they completed an identical drive to the previous, but with a simulated SDSS that provided real-time visual feedback on driver speed.

![Image](attachment://image.png)

*Figure 23. Projected real-time SDSS feedback, denoting an inactive SDSS, active SDSS with driver within the speed limit, and a speeding violation respectively.*

**Smartphone Driver Support System.** For the purpose of the current experiment, which aimed to assess the impact of real-time SDSS visual alerts on driver distraction and behaviour, a simulated SDSS was used, to provide more complex (and realistic) visual feedback alerts. These were broadly modeled on the DriveCam LED feedback system (e.g. Simons-Morton et al., 2013) in which a green light denotes a safe speed within the current limit, and a red light indicates a speeding violation (see Figure 23 above). This simulated SDSS was present on the bottom left of the centre screen, ‘on’ the projected dashboard to resemble the optimal positioning of an actual SDSS as closely as possible (see Figure 24 below).
Dependent Measures.

Peripheral Detection Task (PDT). Participant distraction was inferred via performance on a PDT (Martens & Van Winsum, 2000). These tasks are common, established means of objectively assessing workload during driving, and have been demonstrated to be sensitive to changes in workload and distraction while engaging with in-vehicle information systems (Harms & Patten, 2003; Jahn et al., 2005). While participants were driving, a small red square was presented for one second on the centre television screen in the visual periphery of the driver (see Figure 24 below). Participants were required to respond to the appearance of the square by pressing a marked response button on the steering wheel as quickly as possible (see Figure 25 below). The stimulus appeared at random every 3-5s, at a horizontal angle of 11° to 23° to the left of the subject and the centre of the projected image, and at a vertical angle between 2 to 4° above the horizon. This allowed participants to attend and respond to the stimulus with minimal effort and attention, without needing to turn their head in the direction of the stimulus.

Figure 24. Projected SDSS and red PDT stimulus.

The two PDT specific outcomes measured and recorded by the simulator were reaction time and missed responses or ‘misses’. Reaction time was a measure of the time elapsed between the presentation of the stimulus and the pressing of the response button, recorded in milliseconds. The misses variable was the fraction of missed relative to total PDT stimuli by participants (i.e. when they failed to press the response button). For example, if a participant missed 2 stimuli out of 86 presented, they received a score of .02. A score of 0
Figure 25. Simulator steering wheel with labeled PDT response button.

indicated zero misses, that is, that the participant correctly responded to all of the stimuli presented. Thus, a higher reaction time and misses value were interpreted as indicating greater visual distraction.

_Lateral Position._ Evidence of distraction was also sought by comparing measures of Standard Deviation of Lateral Position (SDLP) over the two drives. The SDLP is typically used in assessing driver distraction (e.g. C. Irwin, Monement, & Desbrow, 2015; Narad et al., 2013; Regan, Lee, & Young, 2008), and is a sensitive vehicular control measure, where increased SDLP scores indicate increased variability and loss of control, denoting distraction. The absolute RMDLP scores for each drive were also calculated and recorded.

_Speed Measures._ As per Studies 4, 5 and 6, participant mean speed was continuously measured by the driving simulator (sampled 10 times per second) during the PDT, and mean speed provided as output. The number of speeding violations was also recorded. These measures were incorporated into analyses to ascertain whether engaging with SDSS feedback improved driver speed or not, and to also potentially provide further evidence of distraction if broken speed limits (i.e. speeding violations) were recorded in conjunction with poor measures of lateral control and PDT scores.

_Demographic Variables._ Demographics and driver behaviour-related information (e.g. age, gender, occupation etc.) as measured by a participant questionnaire was also recorded for the purposes of this study (see Appendix F).

**Procedure**

Participants completed Study 5 (Chapter 7), and were given a short 3-minute break. Following this, they were instructed on how to complete a PDT, and given a 1km practice drive. This was described in detail as per the previous drives they completed (e.g. rural road,
no other drivers present etc.). After this, they were asked to complete a full PDT drive (Time I - Baseline), utilising the same, but extended, driving track (6km in total), which lasted approximately five minutes. In addition, they were informed that during this time, they would be driving with a smartphone app that would be displayed on their projected simulator dashboard (see Figure 24), although this would not be active during the drive. This was so that they could habituate to the presence of the smartphone stimulus, and allow isolation of any potential distraction effects from feedback during the next drive.

Upon finishing this five-minute (approximately) PDT, they were then informed that for the next (and final) experimental Time II drive, the smartphone app (projected on to the simulator dashboard) would now provide them with feedback on their speed. When driving within the speed limit, a constant green light would be observed on the phone (see Figure 24) to indicate this. However, if driving at a speed 10% above (or greater) than the current limit, the phone light would change to red for the duration of this speeding violation. If the participant reduced their speed to within 10% of the current limit, the light would change to green once more. In all other ways, this drive was identical to the drive completed previously, and was again described in detail to the participants before commencement. Once more, the researcher waited on the other side of the room partition while the participant completed the drive.

Following this final drive, the participants were brought out to a desk set up in the corridor beside the simulator lab to complete a final questionnaire booklet. The questionnaire booklet contained a series of demographic and driver behaviour-related questions (e.g. age, years of licensure, number of penalty points etc.) and took approximately 10 minutes to complete. Following this, participants were debriefed orally, and asked to sign a retrospective consent form to signify their willingness for their data to be used in the study.

**D1.5 Results**

*Data Analytic Strategy*

An initial examination of participant data found no missing values within the data set, and the normality of the distributions was then assessed. The violations data, PDT misses and absolute RMDLP scores were subject to square root transformations. The SDLP variables were found to be non-normally distributed, even when subject to transformations, such that non-parametric tests were selected for analyses. Paired samples t-tests were first employed to examine any differences in PDT reaction times between Time I (no feedback) and Time II.
(feedback), and PDT misses. Similarly, differences in mean speed measures, the number of speeding violations and RMDLP scores across the different timepoints were also examined using paired-samples t-tests. Last, the non-parametric Wilcoxon-signed rank test was employed to examine differences across the skewed and kurtotic SDLP variables at Time I and Time II.

Descriptive statistics
Descriptive statistics were first examined with the untransformed data to provide initial indicators as to whether outcome measure data patterns were in line with proposed hypotheses (see Table 25 below). In line with Hypothesis 1, increases in mean PDT reaction time (+0.03) and PDT misses (+0.01) when driving in the presence of the active, feedback providing SDSS versus driving ‘as normal’ during the baseline drive were recorded. Mean SDLP scores were also seen to increase from Time I to Time II (+0.01), while the RMDLP scores remained constant, suggesting findings were partially in line with the directions of Hypothesis 2. Last, participant mean speed was seen to decrease (-1.6km/h), as were the mean number of violations (-5) when real-time SDSS feedback was provided, versus during the Time I drive, again, as per the direction of the proposed Hypothesis 3.

Table 26
Descriptive statistics for dependent variables across time.

<table>
<thead>
<tr>
<th></th>
<th>Time I Drive – SDSS Inactive M (SD)</th>
<th>Time II Drive – Visual SDSS Feedback M (SD)</th>
<th>Change Time I-Time II</th>
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<tbody>
<tr>
<td>Reaction Time</td>
<td>.56 (.06)</td>
<td>.59 (.06)</td>
<td>.03 (.04)</td>
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<tr>
<td>Misses</td>
<td>.01 (.02)</td>
<td>.02 (.02)</td>
<td>.01 (.02)</td>
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<tr>
<td>SDLP</td>
<td>.33 (.11)</td>
<td>.34 (.09)</td>
<td>.01 (.06)</td>
</tr>
<tr>
<td>RMDLP</td>
<td>.17 (.13)</td>
<td>.17 (.13)</td>
<td>.01 (.08)</td>
</tr>
<tr>
<td>Speed</td>
<td>69.58 (5.77)</td>
<td>67.98 (3.54)</td>
<td>-1.6 (4.47)</td>
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<tr>
<td>No. Violations</td>
<td>6.06 (7.38)</td>
<td>1.06 (1.43)</td>
<td>-5 (6.90)</td>
</tr>
</tbody>
</table>

Note: Reaction Time = mean PDT reaction time in ms; Misses = the fraction of PDT stimuli missed during the drive; SDLP = the standard deviation of lateral position scores during the drive; RMDLP = relative mean difference lateral position score; Speed = mean speed in km/h; No. Violations = the number of speeding violations recorded during the drive.

Correlation analysis
Pearson’s correlations (see Table 26 below) were then examined to investigate any
emerging relationships between the variables measured. First, significant positive correlations were reported between each set of the Time I and Time II measurements for the PDT reaction time \((r = .81, p < .001)\), misses \((r = .37, p = .008)\), SDLP \((r = .80, p < .001)\), RMDLP \((r = .81, p < .001)\), mean speed \((r = .63, p < .001)\) and speeding violation \((r = .42, p = .002)\) variables.

In addition to these, significant correlations were reported between the PDT reaction time and missed response variables across the two timepoints, demonstrating that increased reaction times were typically recorded in conjunction with greater numbers of PDT misses. The Time I PDT reaction time and Time I \((r = .46, p = .001)\) misses, and Time II misses \((r = .30, p = .03)\) were observed to be correlated. The Time II PDT reaction time variable also correlated with the Time I \((r = .48, p < .001)\) and Time II \((r = .42, p = .002)\) PDT misses.

The lateral position scores (SDLP and RMDLP) were found to correlate significantly with a number of measures included in the data set. The Time I and Time II SDLP scores correlated with the Time I PDT missed responses variable \((r = .45, p = .001, and r = .30, p = .03\) respectively), with the Time II SDLP variable also reporting significant correlations with the Time II PDT reaction time scores \((r = .29, p = .04)\). Time II SDLP also correlated with the Time I \((r = .38, p = .006)\) and Time II \((r = .47, p = .001)\) RMDLP scores. The Time II RMDLP scores were also found to correlate with the number of speeding violations recorded during that drive \((r = .30, p = .03)\). These findings suggest that reduced control of the vehicle occurred in conjunction with increased PDT reaction times and misses (i.e. evidence of overall distraction).

The mean speed variables were found to correlate positively with the number of speeding violations recorded across the two timepoints. At Time I, mean speed and the number of speeding violations variable correlated highly \((r = .82, p < .001)\). Similarly, at Time II, a medium correlation \((r = .32, p = .03)\) was reported between mean speed and the number of violations variable. Mean speed at Time II also correlated with the number of violations at Time I \((r = .34, p = .01)\).

With regards to demographic and risk related variables, driver age was found to negatively correlate with the Time II PDT reaction times \((r = -.30, p = .03)\), as was the months licensed variable, for both the Time I PDT \((r = -.28, p = .049)\) and Time II PDT \((r = -.30, p = .04)\) reaction time data. Age also correlated with the number of months the participant had been licensed to drive for \((r = .59, p < .001)\), and the number of penalty points they received in the last three years \((r = .38, p = .006)\). The penalty point and months licensed
### Table 27
Pearson’s correlations for dependent and demographic variable scores.

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<tbody>
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<td>1. PDT Rct TI</td>
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<td>2. PDT Rct TII</td>
<td>-.81***</td>
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<td>.48***</td>
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<td>4. PDT Mss TII</td>
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<td>5. SDLP TI</td>
<td>.26</td>
<td>.21</td>
<td>.45**</td>
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<td>6. SDLP TII</td>
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<td>.29*</td>
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<td>7. RMDLP TI</td>
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<td>8. RMDLP TII</td>
<td>.25</td>
<td>.24</td>
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*Note:* PDT Rct TI = mean PDT reaction time for the Time I baseline drive in ms; PDT Rct TII = mean PDT reaction time for the Time II feedback drive in ms; PDT Mss TI = the fraction of PDT stimuli missed during the Time I baseline drive; PDT Mss TII = the fraction of PDT stimuli missed during the Time II feedback drive; SDLP TI = the standard deviation of lateral position scores during the Time I baseline drive; SDLP TII = the standard deviation of lateral position scores during the Time II feedback drive; RMDLP TI = relative mean difference lateral position scores during Time I baseline drive; RMDLP TII = relative mean difference lateral position scores during Time II feedback drive; Mn Spd TI = mean speed during the Time I baseline drive; Mn Spd TII = mean speed during the Time II experimental drive; Viol TI = number of speeding violations during the Time I baseline drive; Viol TII = number of speeding violations during the Time II experimental drive; Mth Lic = number of months licensed; RTC No. = number of RTCs in the past three years; No. PP = number of penalty points in the past three years; Raced = Have you ever raced another driver on a public road (Yes/No); DBQ = Driver Behaviour Questionnaire ‘Violations of Traffic Rules/Speeding’ subscale score. * p < .05, ** p < .01, *** p < .001.
variable also correlated highly with each other \((r = .56, p < .001)\). Last, DBQ scores were also found to correlate significantly with age \((r = .29, p = .04)\) and whether a young driver had raced another on a public road before \((r = .36, p = .01)\).

**Hypothesis Testing**

**Hypothesis 1.** Participants will perform worse (i.e. slower response times, and more missed stimuli) on the PDT when in receipt of real-time visual feedback from the SDSS, than during their baseline drive.

Descriptive statistics (see Table 25 above) demonstrated that, when comparing PDT reaction times while driving with the inactive SDSS (Time I), to driving with SDSS feedback (Time II), these increased from a mean of 0.56ms \((SD = .06)\) to 0.59ms \((SD = .06)\) per stimulus. In order to assess whether or not this change was statistically significant, a paired samples t-test was conducted. Results indicated that this was a significant increase, with a large effect size, \(t(50) = -6.72, p < .001, d = -.94\).

![Figure 26. Increase in PDT reaction times from Time I to Time II](image)

Likewise, scores on the PDT misses variable was seen to increase (from \(M = .01, SD = .02\), to \(M = .02, SD = .02\)) when driving in the presence of real-time SDSS feedback alerts.
Analyses using the transformed variables (in Figure 27 below) confirmed that this was a significant increase, $t(50) = -2.84$, $p = .006$, $d = -.40$. A between subjects ANCOVA confirmed no effects of gender influenced either these findings.

Figure 27. Increase in PDT misses variable from Time I to Time II

**Hypothesis 2.** Participants will demonstrate reduced control over their vehicle (i.e. higher SDLP and RMDLP scores) when in receipt of real-time visual feedback from the SDSS, than during their baseline drive.

An examination of the mean SDLP scores indicated that this increased when driving in the presence of real-time SDSS feedback alerts (Time II, $M = .34$, $SD = .09$) as compared to the Time I drive ($M = .33$, $SD = .11$). A Wilcoxon signed-rank test indicated that this was not a significant increase however, $z = -.10$, $p = .92$.

Similarly, a paired samples t-test confirmed that there was no difference between the transformed Time I ($M = .38$, $SD = .16$) and Time II ($M = .38$, $SD = .16$) scores along the RMDLP variables, $t(50) = -.32$, $p = .75$.

In order to analyse whether gender was potentially influencing outcomes, two separate ANCOVAs were conducted using the lateral position related variables. Given the non-normal distribution of the SDLP variable, any findings in this regard must be treated as tentative. Although no evidence of gender differences emerged along the RMDLP variable, female drivers ($M = .36$, $SD = .10$) were found to have significantly higher SDLP scores than
males \((M = .32, SD = .08)\) during the Time II drive, as indicated by a significant main effect for gender in a between subjects ANCOVA (and controlling for Time I SDLP), \(F(1, 48) = 7.22, p = .01, \eta^2 = .13\). Paired samples t-tests documented a significant increase in SDLP from Time I to Time II for female drivers, \(t(24) = -3.08, p = .005, d = .62\), but no significant increase for males \((p = .40)\). These findings should be replicated in future using non-parametric tests within the R software package.

Figure 28. SDLP and RMDLP scores from Time I to Time II

**Hypothesis 3.** Participants will reduce their mean speed and number of violations when in receipt of real-time visual feedback from the SDSS, as compared to baseline driving, in conjunction with reduced PDT performance and lateral control to indicate compensatory behaviours.

Participant mean speed was documented as decreasing from a value of 69.58 km/h \((SD = 5.77)\) while driving with the inactive SDSS (Time I), to driving at a mean speed of 67.98 km/h \((SD = 3.54)\) when driving with the real-time feedback alerts (Time II). A paired samples t-test confirmed that this was a significant reduction, \(t(50) = 2.56, p < .05, d = .36\).
In line with this, descriptive statistics indicated that the (transformed) number of speeding violations young drivers committed while driving with the inactive SDSS (Time I, $M = 2.32$, $SD = 1.31$) decreased when driving with a SDSS that provided real-time visual feedback (Time II, $M = 1.37$, $SD = .43$). A paired samples t-test confirmed that this was a significant reduction, $t(50) = 5.64, p < .001, d = .79$. No gender differences emerged across these findings.

**Figure 29.** Decrease in mean speed from Time I to Time II

**Figure 30.** Decrease in number of speeding violations from Time I to Time II
D1.6 Discussion

Overview

The overarching aim of this study was to assess whether young drivers experienced distraction when driving with a SDSS that provided real-time visual feedback alerts. Results suggest that young drivers are distracted when engaging with novel SDSS technology, as evidenced by their significantly poorer performance on a PDT while in receipt of real-time visual feedback. Participants were also found to reduce their mean speed and number of speeding violations while driving with the SDSS alerts. In light of the PDT findings, these were likely compensatory behaviours in attempts to manage high cognitive load, dual-task interference and distraction (Birrell & Young, 2011; Saifuzzaman et al., 2015; K. L. Young & Regan, 2007). Of note, the drivers were found to maintain control over the simulated vehicle across both of the drives (i.e. there were no significant decrements in lateral position while driving with the inactive and active SDSS). This may reflect greater ease of control facilitated by the low-fidelity simulator equipment, and the low complexity of the simulated traffic environment, rather than the absence of distraction however.

Peripheral detection task performance

Specifically, it was found that young drivers reacted significantly more slowly to the presentation of the PDT stimulus when driving with real-time visual speed alerts, as compared to their drive with the inactive SDSS. Such a finding indicates that the provision of SDSS feedback resulted in reduced roadway scanning behaviours, as it took participants longer to notice the presence of the PDT stimulus than when they were driving with the inactive simulated device. These results are also broadly in line with previous IVDR distraction-related studies. Martens and van Winsum (2000) for example, reported PDT performance decrements for their sample of 54 experienced drivers when engaging with various forms of real-time feedback (e.g. audio speech messages) on indicators of vehicle lateral control. As young drivers have already been found to demonstrate subpar scanning behaviours (e.g. Pradhan et al., 2005; Pradhan et al., 2014; Senserrick, 2006) as compared to older, more experienced drivers, further reductions in this crucial safety behaviour are particularly concerning. In line with this, significantly more missed responses (i.e. where the young driver was not scanning the periphery to the extent that they missed the 2 second presentation of the stimulus) were reported in the presence of SDSS feedback. Although outside the scope of the current programme of research, it is likely that such findings would have implications for young driver hazard perception responses and performance.
Distraction theory and compensatory behaviours

These PDT findings are also in line with MRT (e.g. Wickens, 2002; 2008). Broadly speaking, this theory states that if two tasks drawing from the same resource stream (e.g. two primarily visual tasks, as in this context) are performed concurrently, dual-task interference occurs to the detriment of performance on either one, or both, of the tasks. As driving is primarily a visual task, and engaging with real-time SDSS visual feedback alerts requires visual input and processing, reductions in vision-related driving behaviours (such as reduced scanning while driving) were anticipated, and evidenced by the poorer PDT scores at Time II. Although drivers are reported to have up to 50% spare visual capacity while driving to engage in certain secondary tasks without detrimental effects, and certain IVDR studies have reported no evidence of distraction with feedback engagement (e.g. see Birrell & Fowkes, 2014; Hughes & Cole, 1986), the extent to which this is true for young, novice drivers is questionable. As suggested by MRT, given the higher demands of the driving task alone for young drivers, their resources are likely more limited and less able to fulfill the demands of engaging with SDSS feedback when in transit, as evidenced here.

Of note, the young driver sample was found to significantly reduce their mean speed by 1.6km/h (SD = 4.47) across the two drives. As previous studies have indicated that reductions in speed of even 1km/h can result in a 5% reduction in RTC risk (M. C. Taylor et al., 2000), and young driver’s heightened vulnerability to negative safety outcomes in relation to speed (Gheorghiu et al., 2015), this could be regarded as a positive finding, in line with the majority of the young driver IVDR efficacy studies published to date, and in line with the SDSS efficacy studies reported in this thesis. In addition, the number of speeding violations committed by the young driver participants were found to decrease significantly during the Time II, active SDSS drive. Driving at a speed that violates imposed limits has long been linked to heightened crash and fatality risk (Alver, Demirel, & Mutlu, 2014; The Royal Society for the Prevention of Accidents, 2016) and so, reductions across this variable could certainly be regarded as a beneficial effect of young driver engagement with real-time, SDSS feedback.

When coupled with the PDT findings however, another interpretation may be warranted. A number of research studies within the broader driving research literature (e.g. Haigney et al., 2000; Poysti, Rajalin, & Summala, 2005; Rakauskas et al., 2004) have attested to the tendency for drivers to engage in a range of conscious or unconscious compensatory behaviours in order to maintain, or attain, an adequate level of safe driving when distracted. This can involve a range of actions such as increasing following distance, to turning down the
volume of a radio (Beede & Kass, 2006; Blomquist, 1986; Strayer & Drew, 2004; Strayer, Drews, & Johnston, 2003). Reducing speed is one of the most common means of compensating for high cognitive load and distraction (Haigney et al., 2000; Rakauskas et al., 2004), and given the findings of the PDT task, which suggest driver distraction, it is possible that the observed speeding reductions are as a result of this. Safe driving does not just denote driving within the confines of the law, or at a particular speed, but that the driver also be able to adequately respond to any upcoming safety-critical situation, in their current state. As such, the PDT findings suggest that the provision of real-time SDSS visual feedback may not necessarily make young drivers drive more safely, as drivers are not as aware of their peripheral visual field and potential hazards, even if they might be driving more slowly.

Of note, no significant performance decrements in lateral control (SDLP or RMDLP) were reported across the two timepoints. This was unexpected, as research typically suggests that lateral position scores are adversely affected when drivers are visually distracted (Engström, Johansson, & Östlund, 2005; Liang & Lee, 2010; Santos, Merat, Mouta, Brookhuis, & de Waard, 2005). It is possible that such findings are indicative of drivers choosing to focus on and prioritise the main driving task and observe the speed limits as monitored by the SDSS, at the expense of their PDT performance, as has been observed in the MRT dual-task paradigm (Horrey & Wickens, 2004; Wickens, 2002; 2008). It is also possible that maintaining lane position is simply easier in the relatively simplistic, low fidelity driving simulator used in this research experiment, and such findings may reflect this. Of note, it was found that SDLP scores were found to increase significantly for female drivers when in the presence of the SDSS feedback, but not for males. Given that no other gender differences were reported across the other distraction variables measured, it is possible that such a finding is spurious. A small-scale instrumented vehicle study ($n = 36$) however, conducted by Lesch and Hancock (2004), found that under induced distraction from mobile phone use while driving, females demonstrated a larger decline in driving performance as compared to males, with respect to greater delays in braking responsivity, and red light noncompliance. Likewise, a series of recent simulator studies featuring young driver participants (J. D. Irwin, Chekaluk, & Geaghan, 2011), demonstrated significant decrements in female driving performance in relation to lateral control and driver errors made while conversing under a variety of phone conversation conditions while driving. Other larger scale studies have failed to document gender differences in driving outcomes due to distraction however (Carney, Harland, & McGehee, 2016; Rumschlag et al., 2015). Further investigation of this finding is needed before definitive conclusions can be drawn.
**Usage considerations**

Smartphone driver support system alerts, like those used in IVDRs are typically ergonomically designed to be as least distracting as possible (Birrell & Fowkes, 2014; Creaser et al., 2011; Creaser et al., 2009). The majority employ simple, familiar visual alerts (e.g. a red light to denote an unsafe manoeuvre, or a speed limit sign to indicate a violation) and/or auditory tones or short voice messages. Emerging evidence suggests that engaging with in-vehicle systems such as these becomes less distracting over time, with practice (e.g. Rouzikhah et al., 2013). This is particularly likely to be the case with young drivers, as their own driving skills improve over time, and the driving task becomes more automatic such that they have greater attentional resources available to safely engage with SDSS feedback. That SDSSs may initially cause distraction is still cause for concern however, as in those initial journeys, a young driver may be putting him/herself and other road users at risk. Training to ensure adaptation to the demands of SDSS usage, as suggested by Creaser et al. (2011) may be necessary before young drivers use a SDSS on-road.

**Limitations**

This research study sought to begin to understand the complex topic of young driver distraction and engagement with real-time SDSS visual feedback, and as such, these findings must be considered in light of certain limitations. First, a simulated SDSS was used, as obtaining/designing a suitable application to work in conjunction with the driving simulator was not feasible within the research programme timeline. Although the simulated SDSS was designed to be as close to a real system as possible (e.g. it was ‘positioned’ on the simulated dashboard, the feedback provided was modeled on a DriveCam IVDR etc.), this study must be replicated using a functioning application to ensure this did not influence distraction-related findings in any way. On-road replication, and longitudinal studies to assess adaptation are also clearly needed to build and expand on current findings. The results from the PDT would suggest that track based research and testing be employed, to ensure the safety of participants and other road users. The simulated drives completed were also relatively simplistic (e.g. no other traffic present, no hazards etc.). As such, that evidence of distraction was still present from PDT scores in this case is noteworthy. Future research must also seek to compare the level of distraction experienced from SDSS feedback with other common distractors (e.g. using a radio), to elucidate the extent of distraction the current significant increase in PDT scores actually signifies (i.e. whether these findings are practically significant). Last, the incorporation of eye tracking software and equipment (Harbluk et al., 2002; Kircher & Ahlstrom, 2010; Zhang & Peterson, 2011) into future young driver
distraction studies would likely prove an invaluable aid to facilitate more definitive conclusions as to the extent to which SDSS feedback is visually distracting from the driving task.

**D1.7 Contribution**

Investigating driver distraction and in-vehicle technology use through a PDT is not a new approach, as is reflected by the number of research studies published in relation to this (e.g. Jahn et al., 2005; Martens & Van Winsum, 2000; Van der Horst & Martens, 2010). Empirically examining young driver distraction in relation to SDSS use is entirely novel however, and represents the first crucial step of the many needed to understand this complex relationship. By using multiple, objective dependent variables to infer and measure distraction, and a driving simulator to provide a controlled traffic environment, this study overcame limitations of previous young driver studies, such as those that have relied on self-report measures (e.g. Creaser et al., 2009) and exposed participants to traffic scenarios of varying complexity during FOTs (e.g. McCartt et al., 2010), advancing the literature. Most importantly, it has highlighted the need for further investigation of young driver engagement with real-time SDSS visual feedback, and cautions that young drivers are likely distracted by real-time alerts upon commencement of SDSS use.

**D1.8 Conclusions**

This study has begun the process of understanding the complex issue of young driver distraction and SDSS use. The findings supported the majority of the hypotheses proposed and consensus of the body of literature relating to driver distraction. These suggest that young drivers are visually distracted while engaging with real-time SDSS feedback, as evidenced by impaired performance on a PDT task when in receipt of real-time visual SDSS feedback. Significant reductions in young driver mean speed and the number of speeding violations while driving with real-time visual SDSS feedback were recorded, however these may have been due, at least in part, to potentially compensatory behaviours due to distraction. Although speed reductions are a desirable outcome of SDSS usage, if they are present due to distraction, young drivers are still at high risk. Although no decrements in lateral control were observed, this may reflect the ease of driving a low fidelity simulator as compared to a more complex set-up or real vehicle. Overall, this study highlights the need for further, comprehensive SDSS piloting, and longitudinal studies of SDSS use to ascertain the impact of engaging with SDSS real-time feedback over time in relation to young driver distraction.
Section D.2: Interim Summary - SDSS Distraction

In line with the hypotheses, the results of this first SDSS distraction study suggest that young drivers experience some level of distraction when first engaging with real-time feedback alerts from SDSS technology. Young driver performance on a PDT was significantly impaired while driving with real-time SDSS feedback, with significant reductions in the number of peripheral stimuli detected, and significant increases in reaction times to these, recorded. In ‘real-world’ terms, this may mean that young drivers using a SDSS, particularly during the initial period of driving with the new technology, are less likely to notice, and more slow to respond to, potential road hazards. This is particularly problematic given their already heightened vulnerabilities to RTCs. Interestingly, significant reductions in young driver mean speed and the number of speeding violations committed while driving with the active SDSS were recorded. Given the PDT findings however, it is possible that this may have been a compensation strategy while dealing with distracting SDSS feedback.

This is the first study to begin to empirically assess young driver distraction from an in-vehicle monitoring device that provides real-time feedback. As such, a number of questions regarding the findings of this study remain, and can be used to inform necessary future research. While currently unknown, for example, it is likely that young drivers will adapt to engaging with the SDSS over time, and particularly if their own driving skills and practices improve (i.e. such that they receive less real-time alerts). Similarly, although a significant reduction in PDT performance was recorded, it is unclear what this actually translates to in terms of RTC risk (e.g. is driving with an active SDSS as distracting as other acceptable in-vehicle activities, such as conversing with a passenger, or listening to the radio?). Longitudinal, on-road replication, in more complex traffic environments is clearly needed before any definitive conclusions regarding young driver SDSS distraction can be drawn.

In all, these findings suggest caution before recommending widespread adoption of SDSS technology that provides real-time feedback alerts to young people. In the absence of additional studies that replicate these findings, and probe the extent to which drivers adapt to this distraction over time however, it is premature to claim that they will lead to increased RTCs.
Chapter 10: Section E.1 - General Discussion

E1.1 Overview of thesis
This final chapter provides an overview and synthesis of the findings from the studies reported on throughout this thesis. It commences with a discussion of the key findings and implications from each of the three themes of the programme of research (i.e. ‘Acceptance’, Section E1.2; ‘Efficacy’, Section E1.3 and; ‘Distraction’, Section E1.4) for the academic and road safety community. Consideration is then given to the potential for Human Factors and Ergonomics research to inform future interdisciplinary SDSS evaluations (E1.5). Last, limitations and avenues for future research are discussed (E1.6), followed by an overall conclusion (E1.7).

E1.2 Acceptance: Findings and implications

E1.2.1 Findings. A number of key findings emerged from the completion of Section B - Acceptance (see Figure 26 below). First, regarding Study 1, while there were methodological limitations associated with the research reviewed, the synthesis of the empirical research suggests that driver monitors and SDSSs can be acceptable to young drivers. Key factors emerging from the review, understood to influence acceptability, were perceptions of usability, accuracy, risks and gains. The findings of Study 1 directly informed Study 2, which tested a novel structural model of SDSS acceptance. From this integrated model, perceived gains and social influence emerged as factors that significantly impact upon a young driver’s willingness and intention to use a SDSS. It also provided an indication of current levels of young driver acceptance of SDSS technology. 

Such findings are, for the most part, in line with previous technology acceptance research studies. Conceptually similar factors to the perceived gains variable, for example, such as ‘perceived usefulness’ or ‘performance expectancy’ (Davis, 1989; Venkatesh et al., 2003), are recognised, established predictors of technology acceptance, lending support to the current findings. These findings have intuitive appeal also, in that gains, such as financial incentives, can off-set the costs of expensive insurance policies, particularly for young drivers facing increasingly expensive costs of cover. Of note, in this context, such incentives may attract drivers not typically motivated by road safety to consider driving with a SDSS (e.g. Lerner et al., 2010; K. L. Young et al., 2003b). These results also resonate with findings in the broader literature on risk mitigation and protective health behaviours, with research showing that perceived gains or benefits can influence intentions to vaccinate.
Figure 29. Key findings from Section B - Acceptance: Studies 1 and 2.

(Teitler-Regev, Shahrabani, & Benzion, 2011), or willingness to perform behaviours to prevent and/or detect skin cancer (Rothman, Salovey, Antone, Keough, & Martin, 1993). Likewise, the power of the peer group, and perceived important others in shaping driving-related decisions and behaviour for this age demographic is also well documented (e.g. on young driver speed selection, Gheorghiu et al., 2015; Pradhan et al., 2014). This is particularly relevant when considered alongside the body of literature indicating the importance of social influence, for all age groups, in predicting technology acceptance of various devices, and applications, such as those designed for smartphone gaming and banking (e.g. Sheppard et al., 1988; D. G. Taylor, Voelker, & Pentina, 2011; Venkatesh et al., 2003; Venkatesh et al., 2012). Social norms have also been documented as influencing adolescent intentions regarding numerous health-related behaviours, ranging from willingness to breast-
feed (Swanson, Power, Kaur, Carter, & Shepherd, 2006) to receiving the influenza vaccine (Painter et al., 2010).

That the broader set of variables in the proposed acceptance model, including perceived risks and perceived usability, did not offer any significant explanatory value in directly predicting behavioural intention was unexpected, although these did report a number of indirect effects throughout, as did the delay discounting variable. It is possible that this reflects the lack of experience young drivers currently have with SDSSs, such that these factors do not become salient for acceptance until in use. There was also evidence to suggest a ceiling effect of perceived usability scores for the young driver participants, which may have limited the predictive utility of this factor. It is also likely that such factors may have a more substantial role to play in predicting actual adoption of a SDSS (behaviour), rather than acceptance (intention). Perceived usability, for example, similar to the perceived behaviour control variable of the Theory of Planned Behaviour, could be more relevant in this context, and in predicting extended usage over time. More sensitive measures of adoption to facilitate modeling and testing these factors are needed going forward.

E1.2.2 Implications. There are two key implications that arise from these findings. The first concerns the need for, and benefits of, conceptual clarity and context-specific models of technology acceptance to maximise explanatory power in research, and better inform practice. The second relates to the potential means through which app providers, road safety bodies, or other stakeholders, can promote and increase young driver acceptance of SDSSs, having identified factors that influence this.

As described throughout Section B, acceptance of new technology encompasses a vast body of research, spanning a number of different disciplines, with multitudes of existing theories and models (Gücin & Berk, 2015; Peek et al., 2014; Venkatesh et al., 2003). This has often meant different disciplines: a) use different terms in reference to the same concept; and/or, b) use the same terms in reference to different concepts (Regan et al., 2014). In reviewing the greater technology acceptance literature prior to conducting the acceptability systematic review (Study 1), and following completion of the review itself, this highlighted the need for conceptual clarity when dealing with technology acceptance, acceptability and adoption, to ensure more valid, better quality research. In line with this, support and a clear rationale for adopting a tailored model approach to conceptualising and examining young driver acceptance of SDSS technology (and indeed, any novel technology) also emerged from the literature reviewed, and the findings of the structural equation modeling analysis (i.e. the
‘excellent’ model fit, invariance across groups, and large amount of variance explained by the structure).

This has implications for the greater technology acceptance literature, and in particular the work of those examining acceptance of novel, or emerging technologies, to aid and inform future research. In addition, given the statistical findings supporting the validity and robustness of the acceptance model and factor scales, this can now be used as an established means to test the acceptance of novel SDSS designs and features, or different levels of an offered financial incentive, for example. Smartphone technology continues to develop at a rapid pace, and with enhanced functionality, more risky driving behaviours may be targeted by this technology in novel ways. However, the extent to which novel features will be deemed acceptable to new users will still need to be assessed to understand how best to promote these. Last, this has provided a starting point through which to consider the role of acceptance in SDSS efficacy (i.e. whether the extent to which a young driver accepts SDSS technology influences how well they drive with it), by providing a more definitive means to conceptualise and measure this, which can be carried forward in future research studies.

Second, the research conducted in Section B has elucidated the factors that influence young driver acceptance of SDSSs, which can be harnessed by, for example, the Road Safety Authority of Ireland, insurance companies, app manufacturers or other relevant parties to maximise future acceptance, and potentially adoption, rates. That is, these findings have implications for the way that SDSSs are advertised and marketed, and can inform targeted persuasive communication strategies, with results pointing to the likely value of targeting perceptions of gains, social influence and lowering perceptions of risk to increase young driver acceptance and usage in particular. In practice, advertisements describing the gains associated with SDSS adoption, for example, or depicting a group of friends favourably commending a peer for driving with a SDSS (i.e. targeting social influence), may serve to enhance prospective consumer acceptance and usage.

**E1.3 Efficacy: Findings and implications**

**E1.3.1 Findings.** The key finding from the SDSS efficacy studies (see Figure 27 below), is that this technology is likely to be effective in reducing extreme driving manoeuvres, and particularly, young driver speed on the roads. Following completion of a
Figure 30. Key findings from Section C - Efficacy: Studies 3, 5 and 6.
systematic review of the young driver monitoring efficacy literature (Study 3), which suggested reductions in risk-taking as a result of engaging with a SDSS, Study 5 examined young driver SDSS use in a driving simulator. This study provided initial ‘proof of principle’ that SDSS monitoring alone could significantly reduce young driver mean speed, and their number of speeding violations, and limited evidence that self-regulation is implicated in this process. To extend the complexity of the SDSS examined in Study 5, and further examine the role of self-regulation and operant conditioning in the monitoring process, Study 6 then confirmed that the implementation of: a) a SDSS with a financial incentive; and, b) a SDSS with a financial incentive and real-time feedback, could significantly reduce young driver mean speed and number of violations above monitoring alone, and also that; c) SDSS feedback alone could significantly reduce speeding violations. Once more, this study provided limited evidence to suggest that self-regulation and operant conditioning underlie this process, and a series of findings to indicate that trait variables (specifically self-regulation, and fear of negative evaluation) may moderate component efficacy of a SDSS.

Such findings are closely in line with previous studies from the driver monitoring literature, and broader research areas such as performance monitoring in the workplace, and the field of health psychology and behaviour change. Of note, the results of Studies 5 and 6 reflect those synthesised in the systematic review (e.g. Bolderdijk et al., 2011; Farmer et al., 2010; Simons-Morton et al., 2013), and particularly those of Creaser et al. (2009), wherein short-term speeding reductions were outlined for teen drivers using a smartphone-based feedback device. Dijksterhuis et al. (2015) also documented young driver reductions in speed and extreme manoeuvres in a driving simulator when financial incentives coupled with real-time/post-journey feedback were provided to drivers via an iPod. The more general driver monitoring literature (i.e. featuring drivers from more diverse demographic groups) has also reported findings in line with those reported here. The work of Mullen et al. (2015), also recorded significant reductions in speed when feedback and an incentive, or an incentive alone was provided to young (< 30 years of age) male drivers via an IVDR in a driving simulator, with smaller scale reductions reported for those solely receiving real-time feedback. Two, on-road IVDR field trials conducted by Regan et al. (2013) and Merrikhpour et al. (2014) of older, experienced drivers also documented similar patterns of behaviour, suggesting that incentives are the main driver in reducing driver speed, and that combining this with real-time feedback also significantly improves outcomes; in line with what self-regulation and operant conditioning theory would propose.
The provision of monitoring, or monitoring in conjunction with feedback and/or incentives has also been reported to significantly improve other behaviours, broadly in line with the driving-specific findings recorded here. As stated, research on the conceptually similar ‘Hawthorne effect’, examining behaviours under monitoring conditions (typically in the workplace), has documented improvements in actions as diverse as providing higher quality patient care, to increased hand hygiene in hospitals, to enhanced worker productivity coupled with electronic performance monitoring (e.g. see Eckmanns et al., 2006; Leonard, 2008; Mangione-Smith et al., 2002; McCambridge et al., 2014). Similarly, in the area of health psychology, a series of recent systematic reviews and meta-analyses have attested to the power of financial incentives in shaping both simple and complex health behaviours, such as reducing smoking, increasing vaccine attendance and screening, physical activity or improving diet to specified standards (e.g. Giles et al., 2014; Kane et al., 2004; Purnell et al., 2014). Likewise, performance feedback has long been recognised as a key motivator of behaviour change, particularly in relation to self-regulation and operant conditioning theory, and prevalent others, such as control theory (e.g. B. Gardner et al., 2010a; Hattie & Timperley, 2007; Webb et al., 2010; Vohs & Baumeister, 2011). Improvements in exercise quality, and corresponding health-related outcomes (M. Lee, Son, Kim, & Yoon, 2015) and enhanced self-management and reduction in somatic complaints for a variety of chronic health conditions, such as irritable bowel syndrome, or Type 2 diabetes (Nes et al., 2012) have been documented upon receipt of tailored, real-time feedback (Hermsen et al., 2016). Such findings attest to the validity of the current findings regarding SDSS efficacy.

**E1.3.2 Implications.** Two implications arise from the research on the efficacy of SDSSs. First, there is a need for theory-led, longitudinal research in this area to better inform the work and policies of stakeholders. Second, a number of conditions under which SDSSs perform optimally have been identified, with corresponding practical implications for design and implementation.

The systematic review (Study 3) revealed a need for better quality, theory-led, SDSS efficacy research to inform the work of stakeholders. Building from this, Studies 5 and 6 were conducted, but limited evidence as to the theoretical mechanisms underlying SDSS efficacy (i.e. self-regulation and operant conditioning) was recorded from these. These indicated that further research, specifically examining this topic, and particularly with more definitive means of measuring and identifying self-regulation and operant conditioning as mechanisms of change, will be necessary to reliably inform implications. Such research could identify more definitive means of harnessing or enhancing SDSS efficacy, for example (e.g.}
to maximise underlying self-regulation, feedback on young driver performance relative to peers could be provided to users), which could then be adopted by SDSS designers and manufacturers when conceptualising their products.

In addition to this, the findings of Studies 5 and 6 highlighted the need for longitudinal SDSS research, in order to examine whether interacting with a SDSS changes its efficacy over time, and whether behaviour change will persist in the absence of a SDSS later in life. Such findings will be of great importance to stakeholders, providing estimates and indications of the overall value of investment in this kind of technology. Of note, the thesis of Creaser recently became available online (2016). This work documents a single, unpublished longitudinal Teen Driver Support System study, which examined the outcomes of three teen driver groups (a control group, \(n = 92\), a real-time audiovisual feedback group, \(n = 92\), and a real-time audiovisual feedback and parental alerts group, \(n = 90\)) when driving with the system over twelve months. Creaser reported that a Teen Driver Support System with real-time alerts and parental feedback reduced risk-taking (including speed) to a greater extent than receiving real-time feedback alone or the control condition, complimenting the findings of the efficacy studies reported here (i.e. regarding the importance of motivation in influencing driving-related behaviour change, and role of feedback in improving outcomes).

This research focused on newly licensed teenage drivers however, with a high level of parental involvement, which means implications for 18-24 year old high-risk drivers cannot be garnered from this. Likewise, empirical examination of distraction, the underlying theoretical mechanisms or moderators of the observed effects, or a post-use examination of driving behaviour was not examined. As such, targeted longitudinal SDSS research addressing these issues is still very much needed to inform stakeholder work and policy.

The findings of Section C have also provided evidence for stakeholders (such as the Road Safety Authority of Ireland, or insurance companies) that SDSSs work, and can be considered an effective and valuable road safety tool in reducing young driver speed. In addition, these findings have identified a number of conditions under which SDSSs can be optimally effective in improving young driver speed. For parties prospectively interested in designing and distributing a SDSS, this research would suggest that a monitoring SDSS offered in conjunction with a financial incentive to carry out (or reduce) the target behaviour may prove optimally effective (at least, in the short-term). Similarly, designing and promoting a SDSS with real-time visual feedback functionality and a financial incentive, may have positive effects on the reduction of speed and violations. Last, evidence of individual differences (i.e. differences in trait self-regulation, and fear of negative evaluation)
moderating the efficacy of SDSS conditions/components was also recorded in Study 7. Given these results, distributors could potentially use these factors to screen drivers, and allow for matching of individuals to personalised SDSS packages designed with features to maximise SDSS efficacy. Such findings will need to be replicated before such an approach is adopted however.

**E1.4 Distraction: Findings and implications**

**E1.4.1 Findings.** Study 7 (see Figure 28) was the final empirical study conducted within the current programme of research, which aimed to begin the process of examining SDSS usage and driver distraction, and from which two key findings emerged. Evidence was provided that young drivers do experience some distraction when first driving with a SDSS and real-time feedback alerts. Second, significant reductions in mean speed and number of speeding violations were recorded when engaging with real-time SDSS alerts. These are viewed as potential compensatory behaviours indicative of distraction, when considered in light of the peripheral detection task findings.

In all, the results of Study 7 are broadly in line with the greater driver distraction literature, and theory, in particular, multiple resource theory (e.g. see J. D. Lee, 2007; Rouzikah et al., 2013; Wickens, 2002; 2008). Previous simulator studies using the peripheral detection task in question, for example, have recorded similar evidence of driver distraction when participants engaged with IVDRs providing real-time feedback (e.g. see Martens & van Winsum, 2000), and young driver self-report data of increased workload/effort, indicating distraction, when engaging with real-time alerts has also been documented (Creaser et al., 2009; 2011; McCartt et al., 2010). Multiple resource theory suggests that the implementation of two primarily visual tasks (in this case, attending to the road ahead while driving, and attending to the visual, real-time feedback provided by the SDSS) would result in decrements in one, or both, of these, particularly for young drivers, given how demanding the driving task is for them at this stage. This was observed in participant’s poorer peripheral detection task performance during the Time II drive, and suggests multiple resource theory may prove a useful framework to guide SDSS distraction research going forward. Also, mirroring previous studies, such as the work of Haigney et al. (2000), Poysti et al. (2005), and Rakauskas et al. (2004), these peripheral detection task results, in line with documented reductions in mean speed and number of violations when driving with real-time SDSS
feedback, suggested engagement in compensatory behaviours during the final drive, due to distraction.

The dangers of, or poor performance outcomes associated with, distraction have been widely documented throughout the driver research literature (Ranney, 2008; Rouzikhah et al., 2013; K. L. Young & Lenné, 2010), with young, inexperienced drivers having been identified as one of the highest risk groups for RTCs when distracted (Buckley et al., 2014; Carney et al., 2015). Similarly, negative outcomes associated with distraction have been reported across other domains within psychology. Distraction in healthcare settings, due to smartphone use by medical residents and attending physicians, for example, has been linked to providing suboptimal patient care, and missed clinical information (Katz-Sidlow, Ludwig, Miller, & Sidlow, 2012). Poorer learning outcomes, such as reduced GPA scores and reduced retention and comprehension of material, due to distraction by social media usage during lectures and/or study periods have also been documented (Gupta & Irwin, 2016; Wood et al., 2012). In addition, numerous lab-based studies have recorded reduced task performance (e.g. recall on memory tests) when in the presence of various distractors (e.g. random auditory stimuli), reporting slower reaction times, greater errors, and overall, impaired performance (Elliott et al., 2016; Farrell et al., 2016; Jääskeläinen et al., 1996; Lange, 2005). Given such findings,
and the multiple studies detailing the heightened risk of fatal RTCs associated with distracted driving for young, inexperienced drivers, the issue of young driver distraction and SDSS use warrants further consideration, and must be key to efficacy evaluations in future, to ensure young driver safety.

**E1.4.2 Implications.** Two key implications emerged from the findings of Study 7. As evidence of young driver distraction with SDSS feedback was reported within this study, the first implication is that SDSS providers should demonstrate that their applications do not lead to distraction for users before making them publically available. Second, and on a related point, there is a need to look beyond, or reconceptualise, ‘efficacy’, and acknowledge that a SDSS that appears to effectively reduce one form of risky driving (e.g. speeding), may also increase another (e.g. driving while distracted).

The finding that young driver engagement with real-time, visual SDSS alerts results in driver distraction has implications for app designers and manufacturers in that novel SDSSs must be subject to more stringent, ergonomic design standards, to reduce their potential for young driver distraction. Of note, it is not yet clear whether these effects are practically significant. That is, it is not yet known whether the significant reductions in peripheral detection task performance actually translate into increased crash risk, or how they compare to other distractors which are generally considered to be acceptable (e.g. listening to a radio while driving). Given the current findings, a focus on real-time feedback modes other than visual alerts, for example, may prove best to limit distraction potential. Extensive pilot testing prior to ‘roll-out’ or implementation must also be conducted, to inform such standards, and in order for stakeholders (such as the Road Safety Authority of Ireland, for example) to ensure their particular SDSS design, features and functionality will minimise levels of driver distraction. Based on Study 7 findings, to ensure safety, such evaluations with young driver participants should be conducted in simulated environments, or potentially following evidence-based practice sessions so participants can adapt to the demands of engaging with real-time feedback, thereby minimising distraction before driving independently on-road.

These findings also attest to the need for SDSS designers, manufacturers and researchers to consider a more holistic view of SDSS efficacy, one which does not focus exclusively on decreases or the absence of specific risk behaviours (e.g. speeding), but also considers other potential impacts that a SDSS can have on the driving task. Safe driving does not just constitute driving at a slower speed, for example, but also being able to detect and respond appropriately to hazards, which has not been considered in SDSS and young driver
monitoring research and implementation to date. In addition, it is crucial that compensatory
behaviours due to distraction (e.g. reductions in speed) are not confused with SDSS efficacy,
or protective value. Although compensatory behaviours are beneficial, in that they reflect the
attempts of a driver to adapt to the increased demand of the current driving and/or concurrent
task, the consequences of distracted driving could outweigh such benefits. As such, the
potential for young driver distraction must be considered in all SDSS efficacy evaluations
going forward.

**E1.5 Reflections on Human Factors and Ergonomics research**

This programme of research was approached primarily through the lens of experimental
social psychology. Such an approach is justified, as the research questions posed were
primarily focused on topics relating to attitudes and beliefs, judgement and decision making,
individual differences, and behavioural change - topics that have traditionally been a focus of
research by social psychologists, and that fit well with an epistemological position that seeks
to better understand individuals in interaction with their social context. Within this literature,
the subject of risk-taking has been explored extensively, including applied problems, such as
the promotion of safe driving behaviours (e.g. Fleiter, Lennon, & Watson, 2010; Kenrick,
Neuberg, & Cialdini, 2010; Petrass & Blitvich, 2014; Ulleberg, 2003). The current body of
work can also be considered to have drawn from the discipline of Health Psychology, in that
it acknowledged and examined the influence of BCTs (Michie et al., 2013; Michie et al.,
2015) on driver behaviour and IVDR use during Study 3 (Chapter 5), and throughout,
adopted experimental design and evaluation processes broadly in line with previous efficacy
studies, such as those used in the area of mHealth (e.g. Chow, Ariyarathna, Islam,
Thiagalingam, & Redfern, 2016; Dute et al., 2016; Beratarrechea et al., 2016; Gandhi et al.,
In Press; Vandelanotte et al., 2016).

However, it must be acknowledged that a holistic understanding of any phenomenon
is best served by research that approaches, or at least demonstrates awareness of, other
disciplines. In this subsection, the thesis looks to research and theory primarily from the
subdiscipline of human factors. This is because some of the studies examined within the
current programme of research could potentially have been explored through the lens of
Human Factors and Ergonomics (‘HFE’; Dul et al., 2012; Karwowski, 2007; Salvendy, 2006;
Wickens, Hollands, Banbury, & Parasuraman, 2013). As such, this section provides a brief
overview of HFE, and the key themes and considerations of this research area. It also
provides a succinct outline of the HFE literature most relevant to the topics of young driver acceptance of SDSSs and in-vehicle technology, the potential efficacy of driver monitor use, and the potential for distraction given this context. Last, it summarises the key messages that can be taken from this field, and applied to the study of young driver SDSS use, with a concise discussion of the implications this has for the study of SDSSs going forward.

**E.1.5.1 Human factors and ergonomics - Definitions and areas of application.**

Human factors and ergonomics research has grown increasingly popular in the past few decades, as technology and work systems have evolved to become ever larger, more complex and interconnected. With this increasing complexity however, came greater vulnerability to systems failures and other negative outcomes impacting on productivity, economic success and safety. Human factors researchers have focused in particular on the role of human error in these negative outcomes - a focus that is justified by a large volume of research that suggests that human error contributes to the majority of technology related accidents in the home, in transit, or at work (Hassall & Xiao, 2015; Wickens et al., 2013).

A series of definitions of HFE as a discipline have been proposed over the past fifty years (Dul et al., 2012), but broadly speaking, it can be described as the study of ‘how humans accomplish work-related tasks in the context of human - machine system operation, and how behavioural and non-behavioural variables affect that accomplishment’ (Meister, 1989, p. 2), including discovering and applying ‘information about human behaviour, abilities, limitations, and other characteristics to the design of tools, machines, tasks, jobs and environments for productive, safe, comfortable and effective human use’ (Sanders & McCormick, 1993, p. 5). According to Dul et al. (2012), HFE research is unique in that it ‘1) takes a systems approach, 2) it is design driven, and 3) focuses on two closely related outcomes: performance and well-being’ (p. 377).

From definitions such as these, it can be understood that the domain of HFE includes: the study of human capabilities and limitations; human-machine interactions; teamwork; tools, machines, and material design; environmental factors; and work and organisational design, all with an emphasis on human performance, safety and satisfaction (Stanton, Hedge, Brookhuis, Salas, & Hendrick, 2004). As these topics span disciplines (e.g. engineering, computing and social sciences), HFE research typically involves multidisciplinary teams, including members from psychology, engineering, representatives from industry, statisticians and data analysts, to anthropometrists.

Traditionally, the most prevalent and cited domains of specialisation within HFE have been physical, cognitive and organisational ergonomics (Karwowski, 2012). Physical
ergonomics refers to human anthropometric, anatomical, physiological and biomechanical characteristics, as these relate to physical activity (e.g. Chaffin & Anderson, 1993; Kroemer et al., 1994; Karwowski & Marras, 1999; Karwowski & Rodrick, 2001). Cognitive ergonomics, focuses on mental processes, such as perception, information processing, memory, reasoning, and motor response, as they relate and impact upon interactions among humans and other elements of a system (Vincente, 1999; Hollnagel, 2003; Diaper & Stanton, 2004). Last, organisational/macro-ergonomics relates to the optimisation of socio-technical systems, including their organisational processes, policies and structures (Karowski et al., 1994; Reason, 1999; Holman et al., 2003; Nemeth, 2004).

On an applied level, multi-disciplinary teams have utilised HFE in a range of settings, dealing with topics such as effective pilot feedback in the cockpit (Palmer, 2007), operator fatigue and its impacts in the railroad enterprise (Sussman & Raslear, 2007), responsivity to alarms in nuclear power plants (O’Hara & Brown, 1991; dos Santos et al., 2013), user acceptance of automation in aviation (Bekier, Molesworth, & Williamson, 2012) to the study of driver workload and stress when driving with a head-up display (Charissis & Papanastasiou, 2010; Liu & Wen, 2004).

**E1.5.2 Human factors and ergonomics and technology acceptance.** Traditionally, within HFE, there has been more of a focus on ‘usability’ than on acceptance or ‘willingness to use’ as a prerequisite to technology adoption (Adelé & Brangier, 2013). It is likely that this reflects the reality that within an organisational context, ‘willingness to use’ is not an issue as it is a job requirement enforced by management. More recently, however, as individuals are increasingly using technologies outside of the occupational and organisational environment, acceptance is becoming more of a concern for HFE research (e.g. Adelé & Brangier, 2013; Rogers, 2012; Wickens et al., 2013). Overall, considerable attention has been given to the study of user acceptance of varying technologies and systems within HFE (e.g. Bekier et al., 2012; Ghazizadeh, Lee, & Boyle, 2012; Mallam, Lundh, & MacKinnon, 2017). Of note, the conceptual ambiguity that has hindered the social psychological literature is also present within the HFE literature, with a variety of terms relating to acceptance used interchangeably, including user ‘satisfaction’, ‘usability’, ‘acceptability’, technology ‘utilisation’ or ‘appeal’ (e.g. see A. Dillon, 2001; Hassenzahl, Platz, Burmester, & Lehner, 2000).

This body of literature has, in the main, had a strong sense of purpose, where theory and evidence on technology acceptance has been generated to enhance design and uptake of new technologies. Here, researchers have primarily considered and tested new theoretical models, seeking to identify key factors that were likely to impact on user acceptance and
reduce the potential for user rejection (A. Dillon, 2001). Key themes here have been ‘compatibility’ (i.e. the degree to which it is in-keeping with social practices and norms among users), and ‘complexity’ (i.e. the extent to which it is easy to use/learn to use) and the extent to which these consistently predict acceptance outcomes (e.g. Tornatzky & Klein, 1982). In particular, the Technology Acceptance Model (TAM) has been frequently employed (e.g. Jia, Lu, & Wajda, 2015; Teh et al., 2015), to examine acceptance of a range of technologies, such as wearable fitness technology (Lunney, Cunningham, & Eastin, 2016), smartphone credit cards (Ooi & Tan, 2016), food traceability systems (Kim & Woo, 2016), to automation (Ghazizadeh, et al., 2012b), from a broad HFE perspective.

One theme of particular relevance to this thesis is that of ‘trust’ in technology. This concept has been included in existing models of technology acceptance, leading to better predictive performance of the new integrated models (e.g. Belanche, Casalo, & Flavian, 2012; Montague & Asan, 2013; Wu, Zhao, Zhu, Tan, & Zheng, 2011). It has been defined as an attitude of confident expectation that in a situation of potential risk (e.g. online banking), that one’s vulnerabilities will not be exploited (Corritore, Kracher, & Wiedenback, 2003), or as ‘the willingness of a party to be vulnerable to the actions of another party, based on the expectations that the other party will perform a particular action important to the trustor, irrespective of the ability to monitor or control that other party’ (Mayer, Davis, & Schoorman, 1995, p. 172).

Trust in technology is an important determinant of reliance on, and acceptance of, technological devices and systems. For instance, it has helped explain acceptance of newly introduced automated systems (Carter & Bélanger, 2005; Ghazizadeh, Peng, Lee, & Boyle, 2012; Gefen, Karahanna, & Straub, 2003; J. D. Lee & See, 2004), willingness to use e-commerce and e-government systems and/or applications (Carter & Bélanger, 2005; Pavlou, 2003), and to use advanced traveller information systems (Xu et al., 2010) for example. It can be based on perceptions or actual usage of the technology/system in question, with any experiences of errors negatively impacting upon it, although this can be restored with error-free usage over time (Corritore et al., 2003; J. D. Lee & Moray, 1992; Muir & Moray, 1996).

This construct was captured in Study 2 (Chapter 4) to some extent by the SDSS perceived risks variables which were included in the final model of SDSS acceptance (e.g. low scores on items such as ‘This app would release my private data without my knowledge/permission’ or ‘This app would record errors and unfairly increase my insurance premium’ could be taken to denote young driver trust in the SDSS technology). However, given its performance throughout the HFE literature, incorporating this construct more
explicitly into future examinations of SDSS acceptance and adoption could prove valuable, and enhance the explanatory value of the existing model tested here.

A construct related to trust is existing user ‘experience’ with technology - which again has been recognised as predictive of technology acceptance and adoption in HFE research (e.g. A. Dillon, 2001). Here, experience with a specific technology is often associated with greater use of that particular device or system (Guinan, Cooprider, and Sawyer, 2010; R. L. Thompson, Higgins, & Howell, 1994). Kim and Maholtra (2005) for example, found that past use positively influenced the perceived usefulness, perceived ease of use, BI (i.e. acceptance itself) and actual usage of an information technology application in their extension of the TAM. It may be that experience leads to greater trust, although this may depend on the particular technology and task characteristics (Ghazizadeh et al., 2012b). Although not directly relevant in the context of the current programme of research and SDSS acceptance model (this was a cross-sectional study of novel technology that none of the recruited participants reported any experience with), it is likely that experience with using a SDSS will influence acceptance and usage rates over time, and should be considered in future modeling studies of SDSS acceptance and adoption, to maximise explanatory potential.

Last, as mentioned previously in Section A2, Chapter 2, HFE and HCI researchers have also examined the ‘lived experience’ of using technology over time (e.g. ethnographic research; Button & Sharrock, 2009; Rogers, 2012). Typically involving qualitative and/or observational research that gathers the real-life experiences of users, this research provides a complimentary, grounded ‘lived’ perspective on technology acceptance and use and can aid: the evaluation of technologies; the understanding of what works and for whom; the impact of the technology on human performance; and future topics for research.

**E1.5.3 Smartphone Driver Support System efficacy and HFE.** Within HFE, there are various theories, and findings from a number of research areas, that can inform the study of SDSS efficacy. In particular, HFE research on the design of effective feedback for safety-related behaviour change when using navigational aids, or head-up displays in cars, to research on alarms in plant control rooms, and pilot cockpits, has resulted in a series of relevant findings that can potentially inform SDSS research, design and use (e.g. Fadden, Ververs & Wickens, 1998; Stanton, 2003; Wickens et al., 2013). To a lesser extent, HFE research on the impact of incentivisation is available (e.g. Sigurdsson, Artnak, Needham, Wirth & Silverman, 2012, Wirth & Sigurdson, 2008), however, this has typically been examined and theorised about in similar ways to those described throughout this thesis (e.g. reporting positive impacts, and highlighting the relationships between goal-setting,
incentives, and the power of motivation). As such, this section focuses predominantly on
what valuable information can be gleaned from the HFE literature regarding real-time SDSS
feedback design.

First, it is worth noting that the study of SDSS efficacy could instead be
categorised/approached from a HFE perspective, as an examination of the potential for
SDSS technology to enhance the Situation Awareness (SA) of young drivers. Situation
awareness, one of the most influential theories of HFE, refers to the degree to which an
operator is aware of the current operational context. More specifically, it relates to the degree
to which an operator can identify relevant cues in the environment, integrate this information
to form a mental model, use this to project the occurrence of events in the near future, and
take appropriate action, incorporating individual, task and environmental factors (Beringer &
Hancock, 1989; Endsley, 2000; Panteli & Kirschen, 2015).

One of the primary focuses in HFE regarding SA is on the development or
modification of technology to facilitate operator SA. The current programme of research has
focused on this, to some extent, through testing and comparing the effectiveness of different
SDSS components (e.g. the provision of real-time feedback alerts) in improving driver
behaviour (e.g. reducing speeding violations), and examining the characteristics of the
operator (i.e. testing potential moderators, such as delay discounting), in influencing this.
From the perspective of future SDSS research however, SA theory provides a useful
framework from which to consider SDSS efficacy in particular. Beyond the moderator
variables examined here, for example, further operator characteristics such as knowledge,
experience, expectations or long-term memory stores (Lo, Sehic, Brookhuis & Meijer, In
Press; Panteli & Kirschen, 2015) may all influence SA when interacting with SDSS
technology and thus impact on decision-making and action (i.e. driving behaviour). Similarly,
established means of measuring SA from the HFE literature could compliment the measures
of SDSS efficacy used in the current work, in future studies (e.g. Kraemer & Sub, 2015; S.
W. Lee, Kim, Park, Kang & Seong, 2016; Lo et al., In Press). Of note, recent work on
distributed SA would promote a more holistic view of SDSS efficacy, in which SA is
distributed across the operator-technology system (Stanton, 2016). Once more, this could
potentially inform the design of future SDSS studies, taking HFE findings on the topic into
account.

The field of HFE also offers more specific, practical information and evidence as to
the optimal design of feedback/alerts for technological displays, which can support existing,
and inform future, SDSS designs. Typically generated from findings in relation to the study
of alarms in control rooms, or head-up displays in planes or vehicles, the benefits of the use of colour, and the use of multiple onsets (e.g. flashing) in enhancing alert salience for example has been recognised, and observed to impact positively upon attentional search (Christ, 1975; Wickens & Rose, 2001; Wickens et al., 2013). A body of work regarding the need to acknowledge the symbolic meanings of colour hue (e.g. red for ‘stop’ or ‘danger’, and green for ‘go’) used in displays, and how this can vary across cultures (referred to as a ‘population stereotype’; e.g. Courtney, 1986), is also of use when considering SDSS design. Incidentally, this body of research would support the selection of a red visual feedback alert to denote a speeding violation, and a green alert to denote safe driving in Study 7 (Chapter 9) for example.

Studies on the use of symbols/icons or pictures (e.g. a speed limit sign, in the context of SDSS use) in feedback or warning alerts have also yielded evidence relevant to SDSS design. For example, research would suggest that such icons should be presented against a high contrast background and should be simple rather than intricate to enable more efficient visual search (McDougall, Curry & de Bruijn, 2000; Huang, 2008). Research has also suggested that where visual warning messages or feedback are used, the use of all capital letters in short phrases or isolated words (e.g. ‘REDUCE SPEED’) is processed better than mixed or lowercase words (e.g. research on computer displays: Vartabedian, 1972; Sheedy, Subbaram, Zimmerman, & Hayes, 2005), and that those with larger blank spaces between words in a phrase are processed more quickly (Van Overschelde & Healy, 2005; Paterson & Jordan, 2010).

Research on the optimal design of auditory alerts has also been conducted, again across usage in power plants, operating theatres, to air traffic control centres and motor vehicles (El Bardissi & Sundt, 2012; Stanton, 2003; Wickens et al., 2013). Key findings include the importance of ensuring that these sounds are significantly distinct from environmental background noises, and each other, and that they are not presented in rapid succession (e.g. McGookin & Brewster, 2004). Studies on whether or not feedback/alerts should be provided as verbal status-related statements (e.g. ‘your speed is above the limit) or commands (e.g. ‘reduce speed’) are also of relevance to SDSS use. Here, however, HFE findings have been relatively mixed. Studies of feedback/instructions provided to pilots when triggered by at-risk flying states for example (e.g. R. M. Taylor & Selcon, 1990; Wickens & Colombe, 2007) found that instructional commands resulted in improved outcomes. A study by Sauer, Wastell and Schmeink (2008), however, found no difference in performance and subjective judgement of usability when presenting participants with command or status
related feedback/instructions when managing a central heating system. Studies by Crocoll and Coury (1990), and Sarer and Shroeder (2001) found that status-related alerts resulted in optimal performance when provided to participants. Clearly this is an issue that needs further examination, as more definitive findings on this subject could be of great relevance to inform the design of SDSSs providing real-time feedback.

The use of augmented reality (often presented via head-up displays) as a means of communicating information and providing feedback alerts is also a topic receiving increasing study in the HFE field (Plavic, Duschl, Tonnis, Bubb & Klinker, 2009), and is of relevance to SDSS use. Some driver monitoring apps (e.g. the iOnRoad app) employ this approach to provide real-time feedback to users. Defined by Azuma (1997) as a means for the ‘user to see the real world, with virtual objects superimposed upon or composited with the real world… augmented reality supplements reality, rather than completely replacing it’ (p. 2), augmented reality systems are understood to have the following three characteristics: 1) combines real and virtual; 2) interactive in real-time; 3) registered in 3-D.

Augmented reality has been used in cars via head-up displays over the windshield to detect and provide information on potential hazards (e.g. Plavic et al., 2009). The technology is also used in gaming headsets (e.g. Van Krevelen & Poelman, 2010; B. H. Thomas, 2012), and by engineers at work where tool components can be labelled in real-time on a head-worn display for example (Henderson & Feiner, 2009). While understood to provide substantial benefits above the presentation of information on a head-down, hand-held display (Yeh et al., 2003), HFE research has identified certain concerns regarding augmented reality use, which should be considered by SDSS designers if adopting this. First, overlaid imagery can cause ‘clutter’, and potentially occlude hazard information (e.g. Beck, Lohrenz & Trafton, 2010; Kaber & Kim, 2011; Kroft & Wickens, 2003; Wickens et al., 2013) and must be designed to strategically minimise this (and particularly so in the case where multiple warnings may appear on-screen). In addition, when presenting information through, for example, a relatively small smartphone screen, this may provide a distorted or biased field of view of the surrounding environment, such that depth perception can be compromised (e.g. Durgin & Li, 2010; Willemsen, Colton, Creem-Regeher, & Thompson, 2009; Witmer & Kline, 1998). Last, the potential for lag, or system latency, must be tested extensively prior to roll-out, as this may provide dangerous discrepancies between the real-world, and the augmented reality presentations (e.g. see Ellis, Mania, Adelstein, & Hill, 2004; Jay et al., 2007; Snow & Williges), leading to impaired performance. For example, it could fail to
provide accurate reports of current speed, or proximity to another vehicle, resulting in increased risk of collision when a driver is relying on it.

Finally, it is worth noting, that, as with studying SDSS acceptance, from a HFE perspective, one could potentially examine SDSS efficacy through investigating the ‘lived experience’ of young drivers engaging with SDSS technology (e.g. Button & Sharrock, 2009; Rogers, 2012). This could involve observation of young people driving with SDSS technology in the traffic environment, and noting their speed for example, to conducting focus groups with young drivers having driven with an SDSS, and enquiring as to how they felt it influenced their driving. Such an approach could potentially compliment the findings of the present thesis and the SDSS literature, if undertaken in a controlled driving environment (for safe observation), and measures to reduce self-reporting bias during qualitative work are deployed.

**E1.5.4 Human factors and ergonomics research and distraction.** While the approach adopted to investigate driver distraction in a SDSS context came from the perspective of experimental social psychology, the theory that informed this, Multiple Resource Theory (MRT), is a prominent theory originating from HFE (Basil, 2012; Wickens, 2002; Wickens, 2008; Wickens et al., 2013) which has been applied to an array of research domains, including aviation and driving (e.g. Wickens, Dixon & Change, 2003). As outlined in Study 7 (Chapter 9), it asserts that multiple, and parallel, processing channels exist at each stage of task processing, with each separate resource channel having limited capacity. Performance decrements are observed when demand for processing resources exceed the available supply within a single channel, when temporally overlapping tasks share a common response modality or stimulus. Given the complex, predominantly visual demands of the driving task for young, more inexperienced, drivers, the introduction of additional visual feedback alerts was found to use visual resources to the extent that capacity was reached, and peripheral detection task stimuli were not observed when driving (i.e. the drivers were distracted from them by the feedback alerts). While extensive information regarding MRT and driver distraction from a HFE perspective has already been outlined within the current programme of research, HFE literature regarding Human Error (HE) and attention can also potentially inform current thinking and future research on SDSS use and young driver distraction.

A large proportion of the HFE literature documents the role of HE in accidents in safety critical systems (Stanton & Salmon, 2009). Human error has been recognised as the primary risk in the aviation sector for example, with estimates suggesting that approximately
60 - 80% of aviation accidents are due to HE (Shappell et al., 2007; Weigmann & Shappell, 1999). Similarly, research suggests that HE in driving is an influential factor for between 75% - 95% of global RTCs (Medina, Lee, Wierwille, & Hanowski, 2003; Rumar, 1990), with HE in the rail network recognised as the dominant cause of accidents in this domain (Madigan, Golightly & Madders, 2016) across the UK (French & Cope, 2012) and Europe (Kyriakidis et al., 2015).

Numerous attempts have been made to define HE within HFE over the past few decades, and while a universally accepted definition has yet to be agreed upon, the majority of these incorporate a focus on any unwanted or inappropriate actions that lead to an undesirable outcome (Young & Salmon, 2012). Reason’s (1990) conceptualisation is a widely used example, wherein HE is described as ‘a generic term to encompass all those occasions in which a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to the intervention of some change agency’ (p.9). The use of formal error classification schemes/taxonomies is widespread throughout most complex safety systems (e.g. in aviation or process control; Stanton & Salmon, 2009). These are used to drive the investigation and analysis of HE, which in turn leads to the development of effective countermeasures. Numerous models and classification systems of HE exist across the HFE literature (e.g. Embrey, 1986; Norman, 2001; Rasmussen, 1982). The most popular is that of Reason (1990), in which he proposed a ‘slips, lapses, mistakes and violations’ error classification scheme.

The most common HEs are ‘slips’. Here, an incorrect action is performed, even though the intention is correct (e.g. erroneously pressing the brake, rather than the accelerator, when intending to increase speed while driving). ‘Lapses’ refer to situations where individuals unintentionally fail to perform some action (often associated with memory failures, e.g. forgetting to lock the car). Both slips and lapses are understood to occur due to issues of attention (e.g. failure to monitor one’s performance at a critical moment in a task). ‘Mistakes’ then, relate to errors at the planning, rather than execution level, when a person intentionally performs an incorrect action (e.g. a driver accelerating towards a red light when they should be braking). Errors occur while individuals are operating within the procedures or rules of system, whereas violations involve intentional or unintentional deviations from these (e.g. driving above the speed limit).

A series of large-scale studies featuring naturalistic and in-depth analyses of RTCs (e.g. Klauer et al., 2006; Sandin, 2009; Staubach, 2009), have confirmed that distraction is a leading factor contributing to driving-related HE, which in turn increases RTC likelihood.
Building from broader HE approaches, driver-specific classifications of HE have been developed (e.g. Treat et al., 1979). Stanton and Salmon (2009) developed a popular taxonomy of driver related HE, identifying five distinct categories of driving error: action errors (e.g. failure to check rear view mirror); cognitive and decision making errors (e.g. wrongly assuming a pedestrian will not cross the road); observation errors (e.g. failure to observe the area in front of the vehicle); information retrieval errors (e.g. misunderstood information presented on road sign); and violations (e.g. intentionally exceeding the speed limit).

According to Young and Salmon (2012), distraction may cause driving-related HE in that, first, it can disrupt typical driving performance variation (e.g. degradation in lateral and longitudinal control), leading to action errors (Andersen, Sauer, & Saidpour, 2004; Caird, Willness, Steel & Scialfa, 2008; Dingus et al., 1995; Engstrom et al., 2005; Santos et al., 2005). It can also diminish visual scanning behaviour and SA, leading to observation errors (such as late detection of hazards, or relevant safety information; Harbluk, Noy, Trbovich, & Eizenman, 2007; Horrey & Wickens, 2007; Klauer et al., 2006). Distraction can disrupt cognitive processing leading to information encoding and retrieval errors (e.g. it can impede memory of speed limit signs; Strayer, Cooper, & Drews, 2004), and negatively impact upon decision-making, leading to cognitive and decision making errors (e.g. engaging in risky gap-acceptance manoeuvres; Cooper et al., 2003). Distraction may also impede error recovery processes employed by drivers, in that they may fail to realise an error has occurred and not initiate a successful response, or they may select an inappropriate response, due to disruption to decision-making processes (Young & Salmon, 2012).

Models of HE, based on taxonomies/classification systems such as these, can be distinguished as ‘person models’ (focusing on models aimed at an individual operator level) or ‘systems models’ (focusing on the interaction between wider systemic failures and errors made by individual operators; Salmon, Lenné, Stanton, Jenkins, & Walker, 2010), which are the dominant approach to understanding HE in HFE (Reason et al., 2008). The HFE and HE literature can thus inform work on SDSS distraction, in that it would advocate a systems approach to understanding distraction-induced, driving-related HE, which has not traditionally been considered in the road safety domain. With a systems perspective approach (e.g. Reason’s 1990 ‘Systems Perspective Approach to Human Error’), error is treated as a systems failure that occurs within a complex system prone to latent or error causing conditions (e.g. inadequate equipment, training, or poor design). As such, in order to fully understand and mitigate against driver distraction and error, future studies of SDSS
distraction should examine the entire driving system, rather than component parts (Stanton & Salmon, 2009). Research should focus on determining what role wider systems factors such as the SDSS device, the design and construction of the vehicle, roadway design and speed limit signage, road rules and legislation for example, play in moderating the relationship between driver distraction and error, and how these elements can be used to mitigate the deleterious effect of distraction.

Last, on the topic of HE, an array of error management methods employed in a HFE context may also be of relevance to prevent SDSS distraction-induced errors in future. Such methods translate knowledge about HE and its causes from classification systems and models, into means of addressing it to, ideally, eradicate, or reduce or mitigate errors and their consequences in safety critical domains (e.g. Embrey, 1986; Young & Salmon, 2012).

Incident reporting systems, for example, are a prevalent method of error management employed in HFE, used to gather data regarding ‘near-miss’ incidents, safety compromising incidents, or errors, and inform preventative strategies. They are common in safety critical fields such as aviation (e.g. the Aviation Safety Reporting System), nuclear power (e.g. the Major Accident Reporting System) or healthcare (e.g. MedWatch) (Salmon et al., 2010).

Such systems function on the premise that near-miss incidents are good indicators of accidents likely to happen in future, and can generate large amounts of data to inform prevention strategies. Adopting an incident reporting system surrounding initial driver SDSS use and distraction-induced errors could provide detailed insights into the different types of error resulting from SDSS distraction, the exact conditions that induce such errors, and any error recovery strategies drivers may engage in when driving with SDSSs.

The use of error databases is a related error management strategy frequently employed in HFE. The Computerised Operator Reliability and Error Database (‘CORE-DATA’) for example, is a database of human or operator errors that have occurred within the nuclear, chemical and offshore oil domains (Basra & Kirwan, 1998). This could be of particular relevance in a SDSS use context, as numerous HFE researchers have identified that IVDRs and other intelligent transportation systems (such as SDSSs) could offer a vast range of automatically generated, high-quality, objective data to populate an error database from consenting drivers. The use of such a structured database when working with SDSSs to examine distraction-induced error could facilitate the in-depth study of error trends, quantitative error analysis and the formulation of effective error countermeasures.

In turning now to the potential contributions of the HFE literature on attention, there are a number of ways in which this research can inform and compliment the study of SDSS
distraction outlined in the current thesis. Defined previously in Study 7, Chapter 9, distraction is the ‘diversion of attention away from activities critical for safe driving towards a competing activity’ (Young, Lee, & Regan, 2008; p. 7). It is, essentially, attentional failure (Lee, Young, & Regan, 2008; Wickens et al., 2013), where attention can be defined as the ‘process of concentrating or focusing limited cognitive resources to facilitate perception or mental activity’ (p. 3). Extensive HFE research on this topic confirms that there are four broad categories of attention: selective, focused, divided, and sustained (Wickens et al., 2013). These categories of attention are critical aspects of life in-and-outside the workplace (Johnson & Proctor, 2004; Wickens & McCarley, 2008).

Frequently described using the metaphor of a flashlight, selective attention can be viewed as a flashlight beam, illuminating/selecting different parts of the internal and external environment in turn. Focused attention relates to the width of the beam, narrow enough to prevent distraction from unwelcome elements. Divided attention can also be conceptualised as the width of the beam, but in the opposite sense, it can be sufficiently wide to accommodate two or more desired channels of information. Sustained attention, finally (as required, for example, on vigilance tasks), can be represented by the battery of the flashlight, maintaining illumination over lengthy periods of time. As outlined previously in relation to MRT, attention is understood to be a limited resource, which impacts on all four categories of attention described above.

Within the vast field of HFE research on attention (Regan, Hallett, & Gordon, 2011; Wickens et al., 2013), there are a number of areas that may be of relevance when considering SDSS use. The study of ‘change blindness’ represents one such area. In general, the human perceptual system is considered to be very sensitive to change in the environment. The visual transients associated with changes (e.g. onset, motion, or flickering) are relatively easy to detect, and typically incorporated in the design of alerting systems for example (Wickens et al., 2013). This is not always the case however, and ‘change blindness’ is the term ascribed to when changes in the surrounding environment are not detected. Within the laboratory, this is usually demonstrated when the change is accompanied by some form of disruption. A blink for example (O’Regan, Deubel, Clark, & Rensink, 2000), a blank screen (Rensink, 2002), or object occluding the scene (Simons & Levin, 1998) have all been found to mask the visual transients that render change salient. In ‘real-world’ settings, change blindness has been observed in pilots failing to notice changes in the flight mode indicator (Sarter, Mumaw & Wickens, 2007) for example, or drivers failing to note changes in street signs (Martens, 2011).
Research has indicated a variety of circumstances that can influence the likelihood that changes in the environment will go undetected. Change blindness is more likely to occur under high workload for example, such as when engaging with attention-demanding, concurrent tasks (Fougnie & Marois, 2007; Lees, Sparks, Lee, & Rizzo, 2007), and is more likely when the individual’s attention is not focused on the area of change before and after the change event (Martens, 2011). When engaging with real-time, visual SDSS alerts during the peripheral detection task in the distraction study (Study 7, Chapter 9), participants noticed peripheral stimuli presented at random more slowly, and were more likely to miss them completely, more often. This could be due to change blindness induced by engaging with SDSS alerts (i.e. they were observing the SDSS, and did not notice the change in the peripheral field), which has obvious negative implications for hazard perception.

Of note, deterring/minimising the potential for change blindness is a key focus of HFE in order to design safety-critical displays for operators in particularly heavily-visual environments. A computational model called the N-SEEV (Noticing-SEEV; Wickens et al., 2009; Wickens, 2012) was developed to identify and quantify the variables that enhance or degrade noticing (i.e. to modulate the magnitude of change blindness for unexpected events). It provides guidance on how to calculate and incorporate factors such as event expectancy (which can also influence change blindness, wherein low expectancy events are less likely to be noticed; Taleb, 2007), and the potential salience of events, and has been found to successfully predict pilot scanning and noticing times (Wickens, McCarley, & Steelman-Allen, 2009). This could potentially be used to enhance future examinations of SDSS distraction, including testing different means of providing real-time feedback, and assess the potential for change blindness when engaging with this.

Research from HFE on auditory attention is also of potential interest to the study of SDSS distraction. While not investigated in the current programme of research, it is likely that auditory alerts will continue to be incorporated by SDSS designers in future, as they continue to be used in IVDRs. Research suggests that the auditory modality differs from the visual in three respects (Wickens et al., 2013). First, noise can be heard from any direction, without needing auditory scanning (or an ‘earball’) to select a location to hear from. Second, the auditory modality can receive stimuli at almost all times, in darkness, or even during sleep (i.e. there is no ‘earblink’). Last, the majority of auditory input is transient, in that a word, or tone, tends to be heard and then ends, as compared to visual input, which is typically more continuously available. As with visual attention however, it is not possible to focus on all auditory stimuli, so attention must be divided among a number of limited auditory events.
(e.g. when an operator must listen to multiple selection channels), or selectively attended to, while ignoring others (e.g. an operator trying to attend to one communication channel, and ignore others). Given the ubiquitous nature of the auditory channel, a warning presented to this has a strong likelihood of being detected, even if the operator is otherwise engaged. However, auditory attention will also be captured by sounds with no relevance or significance, such as when one is distracted by noise in a busy marketplace (e.g. Banbury et al., 2001).

The study of auditory attention from a HFE perspective can potentially inform SDSS auditory alert design, and identify ways to ensure these are effective and attended to, while ensuring they don’t cause confusion, or cognitive distraction, from the driving task. Loud tones, for example, while successfully calling attention to themselves, can startle and annoy (which is often reported in the young driver IVDR literature; McCartt et al., 2010; K. L. Young et al., 2003), and even cause stress, with subsequent poor task performance (Wiese & Lee, 2003). Of note, research on the ‘cocktail party effect’ (e.g. see Cherry, 1953) has demonstrated that individuals have been found to have a low attentional threshold for their own name. As such, low-volume, but personalised, auditory alerts (not presently documented in the IVDR literature), prefaced with the name of the driver may prove a uniquely effective way to attract a driver’s attention to a dangerous manoeuvre, while potentially not causing as much frustration, or distraction from the driving task, than higher-volume approaches, (Sarter, 2009). Research on divided attention is also particularly relevant here, as SDSS alerts are likely to be presented while a radio is playing in the vehicle, such that selective attention may result in their being unattended to. Human factors and ergonomics research has indicated that focused attention on a single channel can be disrupted when two messages appear to come from the same spatial location (Wickens et al., 2013). Simply ensuring that SDSSs are placed in as different a location to the radio/speakers as possible, will enhance parallel processing of in-vehicle noise (radio and alerts) above a monaural presentation of both radio and auditory alerts.

E1.5.6 Conclusions from HFE research. Overall, while not an exhaustive review of the extensive HFE literature, this succinct section has highlighted the potential value of HFE research in complimenting/supplementing evaluations of SDSS acceptance, efficacy and distraction going forward. Throughout, SDSS specific recommendations from the HFE literature have been identified, and potential avenues for future research exploration have been acknowledged. With regards to these three areas of evaluation for SDSSs, a number of themes have emerged within this section. In terms of acceptance, the HFE research reviewed
supported the statistical modeling approach taken in the current programme of research to assess SDSS acceptance, while also highlighting key individual difference factors from the HFE literature which may enhance future means of measuring this. Regarding SDSS efficacy, the value of re-conceptualising and examining this from a situation awareness perspective was acknowledged for future research. Specific recommendations for optimal feedback design from HFE research were also identified, such as how best to structure text-based, visual feedback alerts. Considering the ‘lived experience’ of individuals interacting with SDSSs to provide indicators of acceptance and efficacy was also acknowledged as a potentially valuable future research approach. Last, in terms of SDSS distraction, HFE research on HE and attention have identified classification systems, mitigation strategies, and optimal feedback design recommendations to mitigate any negative outcomes stemming from SDSS distraction, while also reducing the likelihood that these occur in the first place. Overall, while the social psychological approach and literature referenced throughout the current programme of research was the optimal way to address and answer the research questions guiding the present thesis, HFE research and literature does merit consideration for future SDSS research and design, building on the foundation of SDSS empirical research completed here.

E1.6 Methodological limitations and future research

The present body of work has extended the young driver monitoring research literature. Such findings should be considered in light of the limitations of the research conducted however, and study specific issues have been noted within the individual chapters. Some of the more general limitations to the overall series of studies are now outlined, and discussed in the context of recommendations for future research.

E1.6.1 Sample characteristics and generalisability of findings. Although in many ways, the participants recruited for the reported studies represented more relevant, and diverse (e.g. they typically incorporated the full 18-24 high-risk driver age range, and equal numbers of males and females) groups than those examined in previous IVDR studies (e.g. Creaser et al., 2009; McGehee et al., 2007; Farmer et al., 2010), the generalisability of the findings reported is still somewhat limited. The vast majority of the participants recruited (>95%) were students (primarily undergraduates), attending the same university (NUI Galway). While this is not an uncommon issue in psychological research (Gallander Wintre et al., 2001), and in particular with lab-based experimental research, this is a relatively select
sample, wherein participants are likely to have similar socioeconomic status, and live and regularly drive in similar circumstances and locations etc., and as such do not represent the total Irish 18-24 year old demographic. It is unclear as to whether or not factors such as these may influence the findings recorded here (e.g. a financial SDSS incentive may influence SDSS acceptance, and efficacy, in different ways for an undergraduate student versus a working professional, or an unemployed young driver). These findings are also potentially of less relevance to research being conducted in countries such as the USA, where young drivers can receive their full licence and begin driving unsupervised at a younger age. Similarly, although insurance companies have tended to offer this technology predominantly to younger drivers thus far, it is unclear what effects SDSS technology will have if offered to older clientele. Overall, replication of these findings with more diverse participant groups are key to confirm the generalisability of these results and inform future SDSS usage.

**E1.6.2 Ecological validity of the driving simulator and SDSS.** Given the novelty of SDSS technology, and that concerns throughout the road safety literature have been voiced as to the potential for young driver distraction with in-vehicle devices (e.g. J. D. Lee, 2007), it was deemed ethically necessary to examine SDSS efficacy in a driving simulator. Although this bestowed a number of benefits to the studies conducted (e.g. complete control over conditions experienced by each participant, no ‘drop-out’ or data loss etc.), there are limitations inherent to driver simulation research that must be acknowledged (e.g. Klüver et al., 2016; Molino et al., 2005). Although Study 4b was conducted and confirmed the behavioural validity of the driving simulator obtained and used, those analyses were based on simulated driving comparisons with self-report data (the Driver Behaviour Questionnaire subscale measure) rather than on-road measurements of behaviour, and as such the question of the ecological validity of the findings reported remains to an extent. A desktop simulator was also used, which is potentially easier to control than an actual vehicle (of particular relevance when considering the issue of driver distraction and lateral control), and far simpler traffic environments were simulated for participants to drive through (e.g. no other drivers present, as speed independent of other drivers were being examined). In addition to this, a functioning SDSS was not actually used during these studies, due to time and financial constraints relating to designing such an app for use with the simulator. It is possible that using a more aesthetically pleasing or complex SDSS on one’s own phone could be more acceptable, and potentially influence efficacy findings. Future research must conduct on-road trials, in more complex traffic environments with a downloaded, personalised SDSS to provide definitive measures of their efficacy.
E1.6.3 The need for longitudinal research. The studies conducted during this programme of research were designed to examine the initial impact of engaging with a SDSS, to emulate the ‘first drive’ of a young driver, having just downloaded a SDSS for use. While such findings are important, the impact of SDSSs on behaviour over time are equally so, and the current findings are limited by this aspect of their design. While the recently published results of Creaser’s Teen Driver Support System work (2016) provide an excellent insight into the potential long-term effects of driving with a SDSS, a number of questions in relation to this still remain. It is as yet unclear as to whether delayed financial/insurance incentives in particular are sufficient motivators of behaviour change over more substantial periods of time, for example, or the impacts of other potential features (e.g. conditional alerts, or the use of social comparison). Similarly, the role of self-regulation and/or operant conditioning may be better elucidated in a longitudinal context. Young driver acceptance of SDSS technology will also likely change with greater experience of using the app, which in turn, may influence its impact on behaviour, which should be examined. It is also unknown whether young driver distraction when engaging with real-time SDSS feedback abates with time, as driver skill and the automaticity of the driving task increases. Last, to date, no examination as to whether improvements in risky driving remain following a SDSS intervention has been conducted. This should be ascertained, as it could provide further evidence as to the value of a SDSS intervention.

E1.6.4 The need to target other risky driving behaviours. While there was a clear rationale behind the decision to focus on young driver speed and SDSS use (e.g. Gheorghiu et al., 2015), it must be acknowledged that there are a number of other risky driving behaviours that contribute to young driver collision risk, that have not been considered here. Although improper speed use is often implicated in some of these (e.g. extreme manoeuvres such as hard cornering, or harsh acceleration typically involve improper or excessive speed), others, such as driving while intoxicated (Burston et al., 2015), engaging in close following (or ‘tailgating’; Harbeck & Glendon, 2013), driving without a seatbelt (Bao, Xiong, Buonarosa, & Sayer, 2015), driving while distracted due to phone use or eating while driving (Klauer et al., 2006), or driving while fatigued (Scott-Parker, Watson, King, & Hyde, 2012), differ from this, can be motivated by different factors, and also need to be targeted. Currently, in addition to speed-related alerts, SDSSs can provide headway monitoring to alert the driver if they are following a lead vehicle too closely or if a collision is imminent, and lane departure warnings (see the iOnRoad app for example), if the vehicle has strayed from their current lane. The efficacy of the SDSS process on other, or multiple, risky driving behaviours needs to be
examined if young driver road traffic collision risk is to be reduced to as great an extent as possible.

**E1.6.5 Other factors that influence SDSS use.** It must also be noted that there are a vast array of psychological variables that have been examined in relation to, and found to influence, young driver risk-taking and speed, to the extent that a comprehensive test of all these factors was not possible within the time constraints of the current programme of research. While the factors included in the various studies were selected as the potentially most meaningful in the context of SDSS use, it is likely that there are others that may also moderate acceptance of SDSS technology, and the efficacy of engaging with this. Cognitive biases, such as crash-risk optimism (Sibley & Harré, 2009; White et al., 2011), other cognitive factors such as risk perception (Deery, 1999; Rhodes & Pivik, 2011a), and personality traits such as conscientiousness (Arthur & Doverspike, 2001; Arthur & Graziano, 1996; Ehsani et al., 2015), or extraversion (Lajunen, 2001; Renner & Anderle, 2000; Sarma et al., 2013), for example, were not measured or incorporated into the current body of work. Future research may benefit from incorporating variables such as these into efficacy and acceptance studies, and thus extend the young driver SDSS literature further.

**E1.7 Overall conclusions**

A growing number of insurance companies and app manufacturers worldwide are offering SDSSs to young driver consumers, with the promise of reduced insurance premiums for safe driving records, and the provision of real-time and/or post-journey feedback to facilitate this. The findings of this programme of research suggest that young drivers accept SDSSs, and that they have the potential to significantly reduce young driver speeding and road traffic collision risk. Evidence of distraction when engaging with real-time feedback has been observed however, and research now needs to employ strategic longitudinal SDSS field operational tests to understand how acceptance and efficacy of SDSSs, and the experience of SDSS distraction, may change over time for young, at-risk drivers.
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Appendices

Appendix A:

Sample Ethical Approval Letter

Date: 8th January 2014
Re: 13/NOV/02

Ms. Aoife Kervick
School of Psychology
NUI Galway
University Road
Galway

Dear Ms Kervick

Re. Ethics Application:

Examinimg Phone App’ Driver Monitor efficacy – Testing the effects of real-time alerts and financial incentives in moderating young driver speeding.

I write to you regarding the above proposal which was submitted for Ethical review. Having reviewed your response to my letter, I am pleased to inform you that your proposal has been granted APPROVAL.

All NUI Galway Research Ethic Committee approval is given subject to the Principal Investigator submitting annual and final statements of compliance. The first statement is due on or before 31st November 2014. Please see section 7 of the REC’s Standard Operating Procedures for further details which also includes other instances where you are required to report to the REC.

Yours Sincerely

_________________
Allyn Fives
Chair, Research Ethics Committee
Appendix B:
Sample Participant Information Sheet

School of Psychology

Participant Information Sheet

Title of Experiment: Testing novel driving simulator equipment.

Invitation to Participate
You are invited to take part in a research study. Before you decide whether or not to participate, it is important that you understand why the research is being carried out and what it will involve. This Participant Information Sheet tells you about the purpose, risks and benefits of this research study. If there is anything that you are not clear about, the researcher will be happy to explain it to you. Please take as much time as you need to read this information. If you agree to take part we will ask you to sign a Participant Consent Form. You should only consent to participate in this research study when you fully understand what is being asked of you, and you have had enough time to think about your decision.

The Research
This research examines simulated driving. For this study we are recruiting fully licensed male and female participants, between the ages of 18-24, with current insurance, who use a smartphone.

Taking Part – What it involves
Do I have to take part?
It is entirely up to you whether you take part or not. However, if you decide to take part you are still free to withdraw your participation at any time and without giving a reason. A decision to withdraw at any time, or a decision to not take part, will not affect your rights in any way.

What will happen to me if I take part?
If you decide that you do want to participate you will first be asked to indicate via the consent form that you understand the purpose of the study and consent to participate. You will then be instructed to complete a series of drives in the simulator. In between these drives you will be asked to fill out some short questionnaires relating to these drives, and complete a simple computer task. Following this, you will complete a longer questionnaire on a laptop, including demographic and driving related questions.
How long will my part in the study last?
Completing the experiment should take approximately 1 hour.

What are the possible benefits in taking part?
Taking part in this study offers you an insight into psychological research, and the opportunity to experience driving in the School of Psychology’s new simulator.

What are the possible disadvantages and risks of taking part?
There are no foreseeable risks or disadvantages to taking part in this study, however, if you wish to discontinue your participation at any time you are free to do so.

What happens at the end of the study?
After you have completed the experiment, you will be finished with your participation in the study. You will be asked to take your Participant Information Sheet with you, as this explains your role in the study and provides relevant contact details.

What happens if I change my mind during the study?
You are free to withdraw your participation at any point during the study, without affecting your rights in any way.

Who do I contact for more information or if I have further concerns?
If you require any further information about this study, please do not hesitate to contact the researcher Aoife Kervick at a.kervick1@nuigalway.ie.

If you have any concerns about this study and wish to contact someone in confidence, please feel free to contact The Head, School of Psychology, National University of Ireland, Galway or call the department at 091-493 101.

If you have been affected by any way by this research, please contact one of the following services for help/support:

Samaritans: phone 1850 60 90 90 or email ‘jo@samaritans.org’.
If you are an NUIG student, you can also contact the SU Counseling service for free, confidential, professional counseling on 091-492484 or by emailing ‘counseling@nuigalway.ie’.

Thank you for reading this!
Appendix C:
Sample Participant Consent Form

OÉ Gaillimh
NUI Galway

School of Psychology

Participant Consent Form

**Title of Study:** Testing novel driving simulator equipment.

**Researcher:** Aoife Kervick.

**Please tick box**

1) I confirm that I have read the information sheet for the above study and have had the opportunity to ask questions.

2) I am satisfied that I understand the information provided and have had enough time to consider the information.

3) I understand that my participation is completely voluntary and that I am free to withdraw at any time.

4) I agree to take part in the above study.

__________________________   ______________________
Name of Participant          Date                     Signature

Aoife Kervick
Name of Researcher

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Appendix D:
Sample Participant Retrospective Consent Form

School of Psychology

Participant Retrospective Consent Form

Title of Experiment: Testing the impact of smartphone monitoring on driver behaviour.

Researcher: Aoife Kervick.

Please tick box

1) I confirm that the true purpose of this study was explained to me.

2) I am satisfied that I understand the information provided and have had enough time to consider the information.

3) I agree for my data to be used for further research analyses.

4) I understand that my participation is completely voluntary and that I am free to withdraw at any time.

__________________________  _______________   __________
Name of Participant      Date         Signature

Aoife Kervick
Name of Researcher

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Appendix E:
Final SDSS Acceptance Questionnaire

Thinking about the phone application just described, to what extent do you agree with each of the following statements, on a scale of 1–5, where 5 is ‘Strongly Agree’ and 1 is ‘Strongly Disagree’.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Strongly Disagree</th>
<th>Disagree</th>
<th>Neither Agree nor Disagree</th>
<th>Agree</th>
<th>Strongly Agree</th>
</tr>
</thead>
<tbody>
<tr>
<td>This app would be useful when driving</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Using this app would help me to drive better</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Using this app would help me to drive more safely</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Using this app would enable me to obtain cheaper insurance</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Using this app would help me avoid penalty points</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>This app would distract me while driving</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>This app would release my private data without my knowledge/permission</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Using this app would increase my insurance premium</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>This app would record errors and unfairly increase my insurance premium</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>I am confident I could install and update this app on my smartphone</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Statement</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>It would be easy for me to obtain a mount for my smartphone</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have the storage space on my smartphone to install and run this app</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I have the skills and abilities to use this app while driving</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My friends would think highly of me for using this app</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My friends would want to use this app</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other than friends, people who are important to me (e.g. family, co-workers) would think I should use this app</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I want to use this app</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I intend to use this app</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix F:
Standard Participant Demographics Questionnaire

Please provide the information requested in the spaces below. If you have any questions, please let the researcher know. They will be happy to assist you.

1. Age: ________________________________________________________________

2. Gender (e.g. female): __________________________________________________

3. Which of the following best describes your current employment status?
   PLEASE TICK ONE

   - At work full or part time
   - Unemployed
   - Undergraduate student
   - Postgraduate student
   - Engaged on home duties
   - Retired from employment
   - Unable to work for health reasons
   - Other (please specify below)

4. Please provide the approximate date that you received your full, Irish driving licence below (e.g. April, 2012). If you do not have a full licence, but have a provisional one, please state this, and provide the approximate date that you received this below (e.g. I have a provisional licence, April, 2012).

   _______________________________________________________________________

5. Do you personally own a car?
   PLEASE TICK ONE

   - Yes
   - No

6. Whose car do you usually drive?
   PLEASE TICK ONE

   - My own
   - My parent's
   - My employer's
   - My partner's
   - Other (Please specify below)

7. Approximately how many kilometres have you driven in the last 12 months?
   ____________ ____________ ____________ ____________ ____________ ____________
8. In the last 3 years, how many accidents have you been involved in, as the driver of a car, that have resulted in damage to a car and/or injury?

PLEASE TICK ONE

0
1
2
3
4
5 or more

9. Were you found to be at fault in any of these accidents?

PLEASE TICK ONE

Yes
No
N/A

10. Thinking about the most recent accident, what was the primary reason(s) for this accident?

PLEASE TICK ALL THAT APPLY

I was driving when I was tired
I was driving when I was sick
I was driving while under the influence of illegal drugs
I was driving while under the influence of prescription medication
I was driving while under the influence of alcohol
The car ahead of me slowed/stopped suddenly
I was distracted by something happening outside of my car (e.g. an accident on the road, an animal crossing)
I was distracted when using my mobile phone or radio/ music device
I was distracted when consulting a map/ satellite navigation (sat nav) device
I was driving in bad weather conditions (e.g. icy conditions)
I was driving too fast (i.e. speeding)
A mechanical failure with my vehicle was to blame
A problem with the road was to blame (e.g. potholes)
People in the car with me distracted me
An animal in the car distracted me
Other (please specify)

N/A

11. In the past 3 years, how many penalty points have you received?
12. What were these penalty points for?
PLEASE TICK ALL THAT APPLY

<table>
<thead>
<tr>
<th>Penalty Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Learner permit holder driving unaccompanied by qualified person</td>
</tr>
<tr>
<td>Failure to display N Plate or tabard</td>
</tr>
<tr>
<td>Failure to display L-Plate or tabard</td>
</tr>
<tr>
<td>Contravention of ban on U-turns</td>
</tr>
<tr>
<td>Contravention of rules for use of mini roundabouts</td>
</tr>
<tr>
<td>Proceeding beyond no entry to vehicles sign</td>
</tr>
<tr>
<td>Proceeding beyond a traffic lane control sign other than in accordance with such sign or without yielding</td>
</tr>
<tr>
<td>Using vehicle in a public place without an authorisation plate</td>
</tr>
<tr>
<td>Using vehicle in a public place that has been modified or altered such that authorisation plate is inaccurate</td>
</tr>
<tr>
<td>Using vehicle not equipped with a speed limitation device or using a vehicle equipped with a speed limitation device not complying with requirements specified in Regulations</td>
</tr>
<tr>
<td>Proceeding beyond maximum vehicle length sign where length exceeds maximum displayed</td>
</tr>
<tr>
<td>Proceeding beyond maximum vehicle width sign where width exceeds maximum displayed</td>
</tr>
<tr>
<td>Proceeding beyond maximum design gross vehicle weight (safety) sign where design gross vehicle weight exceeds maximum displayed</td>
</tr>
<tr>
<td>Proceeding beyond maximum vehicle axle loading weight sign where vehicle axle loading weight exceeds maximum specified</td>
</tr>
<tr>
<td>Using vehicle (car) without valid test certificate (NCT)</td>
</tr>
<tr>
<td>Parking a vehicle in a dangerous position</td>
</tr>
<tr>
<td>Failure to drive on the left hand side of the road</td>
</tr>
<tr>
<td>Dangerous overtaking</td>
</tr>
<tr>
<td>Contravention of prohibition of driving vehicle along or across median strip</td>
</tr>
<tr>
<td>Failure to stop a vehicle before stop sign/stop line</td>
</tr>
<tr>
<td>Failure to yield right of way at a yield sign/yield line</td>
</tr>
<tr>
<td>Failure to comply with mandatory traffic signs at junctions</td>
</tr>
<tr>
<td>Crossing continuous white line</td>
</tr>
<tr>
<td>Failure by vehicle to obey traffic lights</td>
</tr>
<tr>
<td>Failure to leave appropriate distance between you and the vehicle in front</td>
</tr>
<tr>
<td>Driving vehicle beforeremedying dangerous defect</td>
</tr>
<tr>
<td>Driving dangerously defective vehicle</td>
</tr>
<tr>
<td>Using commercial vehicle without certificate of roadworthiness</td>
</tr>
<tr>
<td>Bridge strikes, etc.</td>
</tr>
<tr>
<td>Holding a mobile phone while driving</td>
</tr>
<tr>
<td>Failure to act in accordance with a Garda signal</td>
</tr>
<tr>
<td>Entry by driver into hatched marked area of roadway, e.g. carriageway reduction lane</td>
</tr>
<tr>
<td>Failure to obey traffic rules at railway level crossing</td>
</tr>
<tr>
<td>Driving a vehicle on a motorway against the flow of traffic</td>
</tr>
<tr>
<td>Driving on the hard shoulder on a motorway</td>
</tr>
<tr>
<td>Driving a vehicle (subject to an ordinary speed limit of 90 kms per hour or less) on the outside lane on a motorway</td>
</tr>
<tr>
<td>Failure to obey requirements at junctions, e.g. not being in the correct lane when turning onto another road</td>
</tr>
<tr>
<td>Failure to obey requirements regarding reversing of vehicles, e.g. reversing from minor road onto main road</td>
</tr>
<tr>
<td>Driving on a footpath</td>
</tr>
<tr>
<td>Driving on a cycle track</td>
</tr>
<tr>
<td>Failure to turn left when entering a roundabout</td>
</tr>
<tr>
<td>Failure to stop for school warden sign</td>
</tr>
<tr>
<td>Failure to stop when so required by a member of the Garda Síochána</td>
</tr>
</tbody>
</table>
### Table of Traffic Offences

<table>
<thead>
<tr>
<th>Offence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure to yield</td>
<td></td>
</tr>
<tr>
<td>Driving without reasonable consideration</td>
<td></td>
</tr>
<tr>
<td>Failure to comply with prohibitory traffic signs</td>
<td></td>
</tr>
<tr>
<td>Failure to comply with keep left/keep right signs</td>
<td></td>
</tr>
<tr>
<td>Failure to comply with traffic lane markings</td>
<td></td>
</tr>
<tr>
<td>Illegal entry onto a one-way street</td>
<td></td>
</tr>
<tr>
<td>Driving a vehicle when unfit</td>
<td></td>
</tr>
<tr>
<td>Breach of duties at an accident</td>
<td></td>
</tr>
<tr>
<td>Speeding</td>
<td></td>
</tr>
<tr>
<td>Driving without insurance</td>
<td></td>
</tr>
<tr>
<td>Driver of Car or Goods vehicle not wearing safety belt</td>
<td></td>
</tr>
<tr>
<td>Failure by Driver to comply with rear seat belt requirements for passengers under 17 years</td>
<td></td>
</tr>
<tr>
<td>Driver of car or goods vehicle permitting child under 3 years of age to travel in it without being restrained by appropriate child restraint</td>
<td></td>
</tr>
<tr>
<td>Driver of car or goods vehicle permitting child over 3 years of age to travel in it without being restrained by appropriate child restraint</td>
<td></td>
</tr>
<tr>
<td>Driver of car or goods vehicle permitting child to be restrained by rearward facing child restraint fitted to a seat protected by active frontal air-bag</td>
<td></td>
</tr>
<tr>
<td>Driver of bus not wearing safety belt</td>
<td></td>
</tr>
<tr>
<td>Driver found to be driving carelessly</td>
<td></td>
</tr>
<tr>
<td>Using vehicle – (a) whose weight un-laden exceeds maximum permitted weight, (b) whose weight laden exceeds maximum permitted weight, or (c) any part of which transmits to ground greater weight than maximum permitted weight</td>
<td></td>
</tr>
<tr>
<td>Drink driving offences (In all cases where the BAC is between 50mg and 80mg 3 n/a 200 of alcohol per 100 millilitres of blood)</td>
<td></td>
</tr>
<tr>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

### Questions

13. Have you ever 'raced' another driver on a public road?

**PLEASE TICK ONE**

- Yes
- No

14. When was the last time you drove a car?

**PLEASE TICK ONE**

- Earlier today
- Yesterday
- During the last week
- During the last month
- During the last year
- More than one year ago

15. Do you regularly drive a manual or automatic transmission car?

**PLEASE TICK ONE**

- Manual
- Automatic
16. How often have you carried out each of these activities below on a scale of 1-5, where 1 is 'Very Often' and 5 is 'Never'. Please circle your answer.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Never</th>
<th>Rarely</th>
<th>Sometimes</th>
<th>Often</th>
<th>Very Often</th>
</tr>
</thead>
<tbody>
<tr>
<td>Break 80 km/h speed limits by more than 10 km/h.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Break 120km/h speed limits by more than 10 km/h.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Overtake the car in front even when it keeps appropriate speed.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Break traffic rules to secure more continuous driving.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Ignore traffic rules to proceed faster.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Drive faster to catch up on an appointment.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>