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Abstract

Cycling is the most energy-efficient mode of transport and can bring extensive environmental, social and economic benefits. Research has highlighted negative perceptions of safety as a major barrier to the growth of cycling. Understanding these perceptions through the application of novel place-sensitive methodological tools such as mental mapping could inform measures to increase cyclist numbers and consequently improve cyclist safety. Key steps to achieving this include a) the design of infrastructure to reduce actual risks and b) targeted work on improving safety perceptions among current and future cyclists.

This study combines mental mapping, a stated-preference survey and a transport infrastructure inventory to unpack perceptions of cycling risk and to reveal both overlaps and discrepancies between perceived and actual characteristics of the physical environment. Participants translate mentally mapped cycle routes onto hard-copy base-maps, colour-coding road sections according to risk, while a transport infrastructure inventory captures the objective cycling environment. These qualitative and quantitative data are matched using Geographic Information Systems and exported to statistical analysis software to model the individual and (infra)structural determinants of perceived cycling risk.

This method was applied to cycling conditions in Galway City (Ireland). Participants' (n=104) mental maps delivered data-rich perceived safety observations (n=484) and initial comparison with locations of cycling collisions suggests some alignment between perception and reality, particularly relating to danger at roundabouts. Attributing individual and (infra)structural characteristics to each observation, a Generalized Linear Mixed Model statistical analysis identified segregated infrastructure, road width, the number of vehicles as well as gender and cycling experience as significant, and interactions were found between individual and infrastructural variables. The paper concludes that mental mapping is a highly useful tool for assessing perceptions of cycling risk with a strong visual aspect and significant potential for public participation. This distinguishes it from more traditional cycling safety assessment tools that focus solely on the technical assessment of cycling infrastructure. Further development of online mapping tools is recommended as part of bicycle suitability measures to engage cyclists and the general public and to inform ‘soft’ and ‘hard’ cycling policy responses.

Keywords: cycling; perceived risk; safety; mental mapping

1. Introduction

Cycling safety is receiving increased attention as researchers, transport planners and cycling advocates seek to increase uptake of the mode. A Stop Killing Cyclists protest (or ‘die in’) by more than 1,000 cyclists in London in November 2013 dramatically highlighted the continued risk of fatalities (The Guardian, 2013), and called for more suitable roads for cycling. Cyclists are classed as ‘vulnerable road users’; in 2010, 1994 cyclists were killed on the roads of 20 EU countries. Although cyclist fatalities in Europe have declined over the last decade, cyclists remain among the most vulnerable road users. Furthermore, the decline in cycling fatalities has not been as steep as for other road users, and cyclists now account for a greater proportion of overall road fatalities at 7% (ERSO, 2012).

Perceived cycling safety acts as a major barrier to increasing cycling (Pucher & Dijkstra, 2000). According to Parkin et al. (2007a): “While actual, or objective risk, is relatively high for cycling compared with other modes, the perceived risk, that is the risk that is assumed to exist by existing and would-be mode users, is the important criterion in terms of behavioural response". This applies equally to people's decision to cycle at all, their choice regarding particular routes (e.g. avoiding roundabouts) as well as their actual behaviour (e.g. lane position). Consideration of perceived safety is also central to successful cycling design (Parkin & Koorey, 2012), yet there has been a lack of research into both the objective characteristics of cycling environments as well as cyclists' perceptions of these environments (Ma et al., 2014).

Mental mapping is a research method that offers ample potential for recording and analysing safety perceptions but which has not yet been fully utilised. This paper uses mental mapping as part of a mixed-method approach to capture perceptions of cycling safety and their relationship to the physical environment. By matching qualitative data on the perceived quality of the cycling environment to quantitative and qualitative data on the physical environment, the paper 'unpacks' major determinants of perceived cycling risk. This is tested against a case study carried out in Galway, a university city in the West of Ireland. The methodology and results of this paper will be relevant to engineers, planners, policymakers and cycling advocates as part of an interdisciplinary response to improving actual and perceived safety and increasing sustainability in transport.

2. Literature Review

2.1 Environmental Perceptions and Travel Behaviour

The relationship between environmental perceptions and spatial behaviour has interested social scientists for decades. In the field of transport studies~~,~~ and traffic psychology, a body of work~~a small, but emerging, body of literature~~ contends that attitudes, perceptions, and preferences strongly influence individual's travel behaviour, including recent contributions from ~~(~~Spears et al.~~,~~ (2013) and~~;~~ Gehlert et al.~~,~~ (2013). Indeed, ~~recent~~ several studies have indicated that attitudes towards public transport as well as concerns about personal safety and traffic all play a significant role in the decision to use public transport (Elias & Shiftan, 2012).

~~Within t~~Transport ~~studies,~~ researchers have applied attitude and behavioural theories from environmental and cognitive psychology, such as Fishbein & Ajzen's (1975) *Theory of Reasoned Action* (TRA) and later Ajzen's (1991) *Theory of Planned Behavior* (TPB), to explore the psychological dimensions of travel behaviour and modal choice. The TRA and related models from the field of cognitive psychology assume that individual variables such as attitudes and perceptions are the dominant drivers of behaviour (this approach has been advocated for promoting bicycle use by Bamberg (2012). A number of empirical studies support this contention (e.g. Thogerson (2006)).

While often contested, the influence of perceptions cannot be ignored. Geographical and sociological studies of crime in cities and perceptions of neighbourhood safety (Rengert & Pelfrey, 1997; Austin et al., 2002) have shown that perception is often more important than objective reality in shaping people's use of the built environment, including transport infrastructure and services. However, approaches derived from the TRA and similar theories have increasingly been criticised for overstating the influence of perceptions and almost completely neglecting of the role of structural and contextual factors in shaping individuals' behaviour (Nye & Hargreaves, 2009; Davies et al., 2014). As a result the past decade has seen the growth in perception behaviour models which incorporate contextual and situational factors. For example, the premise of Spears et al.'s (2013) *Perception-Intention-Adaptation* (PIA) model is that both cognitive processes and the physical environment have a direct effect on travel behaviour. Similarly, Kazig and Popp (2010) have argued for a practice-theoretical approach to how people orient themselves in urban spaces which combines cognitive and affective aspects as well as elements of the (infra)structural context.

2.2 Cycling Risk

2.2.1 Cycling Safety and Perceptions

Safety is the primary factor in choosing whether to commute by bicycle (Noland, 1995; Whannell et al., 2012). The major cause of cycling collisions is interaction with motorised vehicles: 82% of cyclist fatalities and 87% of cycling injuries occur in collisions with motorised vehicles (ERSO, 2012). Junctions pose a particular danger to cyclists: 35% of cyclist fatalities take place at junctions, compared to 20% for pedestrians and 17% for car users (ERSO, 2012). The main injuries to cyclists are to the legs, head and arms and the most common types of injury are fractures (34%), bruising (31%) and open wounds (13%). Injured cyclists spend, on average, an extra day in hospital than those injured in car collisions (ERSO, 2012) and are classed as 'vulnerable road users'. An uptake in cycling is seen as particularly important from a road safety perspective as the 'Safety in Numbers' theory holds that the likelihood of cycling collisions is inversely related to levels of cycling (Jacobsen, 2003).

Perception of cycling safety may be more important than objective reality in determining uptake of cycling. These perceptions are influenced by attitudes, social norms and habits (Heinen et al., 2010; Ma et al., 2014). Drivers' attitudes to cyclists, for example, present a significant barrier to cycling (Lawson et al., 2013; Wooliscroft & Ganglmair-Wooliscroft, 2015). Cyclists themselves consider many more factors than users of other modes (Fernández-Heredia et al., 2014). Horton's (2007) 'fear of cycling' goes beyond that of collisions and traffic to include the fear of being on show, of harassment or violence, and of seeming inept or unfit. Many of these fears are culturally embedded and socialised, e.g. parents constrain the travel behaviour of their children based on risk perceptions (Timperio et al., 2004; Carver et al, 2010). Collective perceptions of risk also manifest in social pressure to wear disliked safety clothing, such as high-visibility vests and helmets (Aldred & Woodcock, 2015; Deegan, 2015); however, these do not improve perceptions of safety among cyclists (Lawson et al., 2013).

To date, few studies of perceived cycling risk have included the characteristics of the cyclist (e.g. age, gender and cycling frequency) (Lawson et al., 2013; Black & Street, 2014; Bill et al., 2015), which is a gap that this paper seeks to address. The UK Department for Transport considers the perception of cycling risk as a potential barrier to cycling and includes perceived cycling safety in the British Social Attitudes survey (UK DfT, 2014). 61% of people in the UK consider the roads to be too dangerous to cycle on and this varies with age (47% of 18-24 y/o, 76% of 65+ y/o), gender (69% of women, 53% of men) and cycling experience (48% of those who cycled in the last year, 67% of those who did not) (UK DfT, 2014). Several studies identified *age* and *gender* as factors which influence perceptions and which also shape responses to segregated cycling infrastructure (Garard et al., 2008; Black & Street, 2014; Ma et al., 2014; Dill et al., 2015). Cycling experience has also been shown to influence risk perceptions and ~~Frequent~~ inexperienced cyclists are more likely to perceive road conditions as hazardous (~~cyclists were found to have better perceptions of the cycling environment (Ma et al., 2014;~~ Bill et al., 2015). Sanders (2015) suggests that additional experience and skills gained may make these cyclists more tolerant of risks, although even experienced cyclists are concerned about a variety of possible causes of injury.

~~and are more likely to fear more commonly reported actual collisions, while infrequent cyclists are more likely to be affected by near misses (which Sanders (2015) demonstrated to have a stronger effect than actual collisions).~~

2.2.2 Infrastructure

Many authors, across various disciplines, have examined the connection between the built environment and cycling behaviour. Key infrastructural and traffic factors that affect perceived cycling risk include: motorised traffic volume and speed, presence of cycling facilities, driving lane width, number of junctions and roundabouts, pavement surface, parked cars and traffic mix (Lawson et al., 2013; Bill et al., 2015). Increased perception of cycling crash risk can be found in areas of low density, non-mixed land uses as opposed to compact, mixed-use neighbourhoods. This was even found when the latter areas experienced greater actual crash risk (Cho et al., 2009). Bicycle-friendly neighbourhoods (connected streets, low-traffic etc.) improve residents' perceptions of the environment and these residents cycle more often due to these positive perceptions (Ma et al., 2014).

Major streets with shared lanes are associated with greatest perceived risk while shared-use paved paths are considered the safest form of infrastructure (Winters et al., 2012). Parkin et al. (2007a) found that cycling facilities at roundabouts did not reduce the perceived hazard. Cycling infrastructure on roads with heavy traffic marginally reduced perceived risk, while completely off-road, traffic-free routes significantly reduced this perception. Cycle tracks are perceived as the safest form of cycling infrastructure, preferred to raised cycle lanes, cycle lanes, and on-road in traffic in Copenhagen (Jensen et al., 2007). Approximately 45% of respondents felt 'very safe' cycling on cycle tracks, compared to 32% on cycle lanes and 11% on road in traffic. These results confirm existing evidence of cyclists' preferences for segregated infrastructure, although there are limits to the additional travel time that cyclists are willing to spend in order to use segregated infrastructure (Sener et al., 2009; Caulfield et al., 2012).

2.2.3 Existing measures of cycling risk perception

The landscape of existing measures of cycling risk perception shows clear tendencies towards infrastructural and technical considerations for practical application in traffic engineering and urban design, e.g. cycling level of service (LoS), facility suitability, friendliness and compatibility. The empirical backgrounds of these measures typically model infrastructural and traffic factors associated with perceived risk (e.g. road width, traffic volume). Such measures are useful as road sections can be rated and mapped to assist cyclists in route choice and identify route sections in need of improvement. To clarify inconsistent terminology and to classify measures spatially, Lowry et al. (2012) proposes three definitions:

- ‘bicycle suitability’ (perceived comfort and safety along a *linear section* of road)
- ‘bikeability’ (comfort, coherence, and convenience of a bicycle *network*)
- ‘bicycle friendliness’ (laws, policies, education, bikeability of a *community*)

Lowry et al. identified 13 measures of ‘bicycle suitability’ developed between 1987 and 2011 (e.g. Bicycle Compatibility Index (Harkey et al., 1998)), which vary according to infrastructural characteristics considered, points system and weighting (see Parkin & Coward (2009) for a review of cycle route assessments). Factors considered in these measures are: road facility type; lane width, number and markings; cycle facility type and width; motorised traffic volume and speed; cyclist traffic volume and speed; percentage of heavy vehicles; presence of on-street car parking; number and type of junctions/driveways; pavement condition and presence of a curb. The factors are weighted as adjustment factors and combined to yield a score for bicycle suitability or perceived comfort or perceived safety.

The data collection methods for 13 perceived cycling safety studies have also been summarised by Lawson et al. (2013) to include: video recordings, video simulations, completion of a test course, interviews and questionnaires (see Doorley et al. (2015) for a novel application of heart rate monitors in the assessment of perceived risk). However, only two of the studies reviewed by Lawson et al. (2013) considered the characteristics of the cyclists: Møller & Hels (2008) and Noland (1995). Møller & Hels investigated cyclists' perception of risk at roundabouts, finding that safety perceptions are determined by a combination of the characteristics of the individual cyclist (age and gender), the design of infrastructure (e.g. cycle facility) and traffic volume.

2.3 Mental Mapping: Visualising Cycling Risk Perceptions

To better understand road safety perceptions among cyclists requires a combination of methods of data collection and analysis that can handle both quantity and quality. Importantly, the successful application of videos, computer simulations, interactive maps and other visual aids points towards the key role of visualisation in road safety research (cf. Prendergast & Rybaczuk (2005) for a more general discussion of visualisation in spatial planning). Mental mapping, a creative process that seeks to draw out and subsequently visualise people's experiences of their physical and social surroundings, deserves particular attention in this context.

Mental maps are defined as "an amalgam of information and interpretation reflecting not only what a person knows about places but also how he or she feels about them" (Johnston et al., 1986). While all maps can serve as texts for exploring human perceptions of the landscape (Soini, 2001), mental maps in particular have long been associated with cartography that explores human perceptions of landscape. Lynch's (1960) research on images in the city represents an early landmark study in this field that reveals how different social groups view and respond to the same environment in diverse ways. Mental maps have served to explore a range of subjects including perceived desirability of neighbourhoods, orientation and way-finding, perceptions of crime and migration propensities (Gould & White, 1993; Fahy & Ó Cinnéide, 2009).

Growing interest across a range of disciplines in representations and the social construction of places has coincided with an increased appreciation of mental mapping (Gregory, 2009). From a land use planning perspective, approaches incorporating mental mapping offer significant advantages over survey methods or other scale-based measures because of their place-specific attributes (Brown and Raymond, 2007). Indeed, Brown and Raymond (2007: 108) argue that "the mapping of landscape values and special places can provide an operational bridge between place attachment and applied land use planning that seeks to minimize potential land use conflict".

Research into mental maps and travel behaviour is sparse and existing studies focus predominantly on travel route choice. As noted by Mondshein et al. (2010:849): "the limited research to date suggests that transport infrastructure and way-finding on overlapping, distinct modal networks – sidewalks, bike lanes, transit routes, local streets and roads, and freeway networks – affect the development of cognitive maps and, in turn, travel behaviour". The limited research on transport and mental mapping that exists suggests that mode of transport influences level of detail and quality of maps, which has significant implications for transport planning, accessibility, and wider public policy (Mondshein et al., 2010, 2013). For cyclists, Snizek et al. (2013) used mental mapping to study route experience in a 'high cycling' environment in Denmark, whereby an online questionnaire in Google Maps allowed participants to award positive and negative experience points. Their approach points to a wider field of online GIS-based platforms and sensors for crowd-sourcing perceptions of cycling safety and identifying localised risks (cf. Loidl (2014), Nelson et al. (2015) and Zeile et al. (2015)). However, Snizek et al. (2013) did not consider the individual characteristics of the cyclists and the effect that these may have on route experience. The following section details our own methodological approach which responds to both opportunities and gaps identified in the literature review.

3. Methodology

This study combines mental mapping, a stated-preference survey and a transport infrastructure inventory to unpack perceptions of cycling risk and to make visible both overlaps and discrepancies between perceived and actual safety risks. The results of mental mapping and the stated-preference survey captured perceptions of the cycling environment, while a transport infrastructure inventory collected characteristics of the objective cycling environment. The resulting qualitative and quantitative data were matched using Geographic Information Systems and exported to statistical analysis software to construct a model of the individual and structural determinants of perceived cycling risk. In this context this paper makes a significant contribution to cycling safety research by exploring the perceptions of cycling risk through the application of mental mapping as part of a larger mixed-method study.

3.1 Study Area

Ireland has established a national cycling target of 10% modal share by 2020, yet safety concerns remain a major impediment to increasing cycling uptake (DTTAS, 2009a; 2009b). Between 2013 and 2014, there was a 27% increase in vulnerable road user deaths; there were 12 cyclists killed in 2014, compared to 5 in 2013. Cyclists represent 6% of all road fatalities despite accounting for only 2% of road users (RSA, 2014). Issues surrounding cycling safety are gaining attention in the Irish media as shown by one recent current affairs programme entitled 'The growing war between cyclists and motorists, what's happening on our streets?' (RTÉ, 2015). This discourse has centred on conflicts between the behaviour of cyclists (breaking red lights, cycling on footpaths) and the behaviour of motorists (aggression, verbal abuse, speeding, dangerous driving). Short & Caulfield (2014), for example, discuss the safety challenge of increased cycling and the incorporation of safety in policy.

To achieve the national cycling target, small, compact urban areas with a young population are deemed to harbour significant potential for modal shift away from the car and towards active travel modes. The present study was conducted in Galway, a university city of 75,000 people on the west coast of Ireland. The study area is affected by a number of issues that might impede uptake of cycling and a recent qualitative study that investigated modal shift among the workforce of a large employer found perceived safety risks in the city to be an important barrier to walking and cycling (Heisserer, 2013). Galway experiences mean annual rainfall of 1193 mm and the mean annual temperature is 10°C (Met Éireann, 2015). The city has a cycling modal share of 5%, while 57% residents travel to work by car, either as a driver or passenger (CSO, 2012). Recent cycling-related developments include the installation of raised cycle lanes, a series of greenways and a bike-share scheme.

3.2 Survey Sampling

In this study, people in Galway City who cycle to work, school or college make up the study population. Convenience sampling was utilised by presenting the paper-based survey to potential participants at large events in 2013; (random sampling techniques (e.g. simple random, cluster or stratified sampling) could not be generated due to the lack of a sampling frame; an intercept survey was also deemed unfeasible due to the time required to complete the survey). The National University of Ireland, Galway campus was chosen for its central location (1 km from Galway City centre) and relatively large cycling population (cycling modal share 12%, campus population 17,000 students and 2,000 staff (Manton and Clifford, 2012)). As the sample was not randomly selected, it was not possible to make statistical inferences about all cyclists or indeed the population of this study (Smith, 1983); however, the use of non-random samples does not necessarily compromise the generality of the results, allowing for interesting quantitative findings to be generated (cf. Chow, 2002).

3.3 Mental Mapping

While traditional mental mapping studies asked participants to draw a freehand sketch (Lynch, 1960), this study utilised a base-map of Galway City roads and streets as an assist. Participants were provided with one map each (which included a brief written introduction, outlining the task) and coloured pens. They were asked to draw their regularly used (at least weekly) cycling routes and to colour each route section according to their perception of the safety of that section of their route: *Green* for safe, *Amber* for unsafe, and *Red* for very dangerous. The use of this traffic-light sequence allowed for easy expression of risk, compared to more complex rating scales. Participants found their origin and destination on the base map and translated their mental map into coloured ratings of risk along the route. The mapping task was undertaken independent of any interaction with the researcher and there were no time restrictions placed on any of the participants. Participating in this mental mapping exercise offered respondents a chance to reflect on their everyday cycling practices and to offer some practical local improvements.

3.4 Stated-Preference Survey

Following the mental mapping exercise, participants completed a stated-preference survey of 28 questions that reflected the findings of the reviewed literature. Questions on participants' general cycling experience and preferences (e.g. cycling frequency, trip purpose, self-ascribed cycling skill, typical infrastructure used, preferred infrastructure) preceded questions on cycling safety, including involvement in road collisions. The order of questions was designed to invoke the memory of any previous cycling collision before the participant answered specific questions on factors affecting cycling safety, including the volume of cars passing, volume of trucks passing, roundabouts, adjacent car parking, speed limits, road lane width, cycle lane width, and number of junctions. Due to the level of detail involved in these questions, participants were challenged to carefully consider each factor before ranking them in order of importance. Finally, participants were asked to provide demographic details including: age, gender, years spent living in Galway, employment status, household composition, and car availability.

3.5 Transport Infrastructure Inventory

Data on infrastructural and traffic-based factors affecting safety were collected using a transport infrastructure inventory of Galway City. These included traffic volumes (cars and the proportion of HGVs), on-street car parking, cycling facilities, road width, and junctions. The roads in the study area were divided into sections of similar length(generally between junctions and using named roads where possible) and data on each road section were collected through desk studies and site visits. The volumes of light vehicles (predominantly cars), heavy vehicles (predominantly trucks) were retrieved from Galway City Council (2013), based on annual traffic counts conducted between 7am and 7pm on a standard day in November. The locations of adjacent car parking were identified on site and by using Google Streetview. The speed limit on all roads was 50 km/h, with the exception of the NUI Galway campus, which has a speed limit of 20 km/h. The locations of segregated cycling infrastructure were identified from Galway City Council (2012). The widths of road and cycle lanes were measured on site. The number of junctions in each road section was counted from mapping. A shapefile of the road network was imported to ArcGIS and the polylines were split according to road section and inventory data were then added as attributes to each road section. Limitations to the assessment of perceived safety include the under-reporting of cycling collisions, the avoidance of particular routes and the variation in route types and location (Parkin et al., 2007a).

3.6 Data analysis

This final stage of the empirical part of the study constructed a model of perceived cycling risk by matching the perceived environment (mental map) to characteristics of the physical environment (inventory data). Mental maps were uploaded to ArcGIS by attributing the colour-coded ratings of each participant (along with demographic information) to road sections (cf. Boschmann & Cubben (2014) for sketch maps and qualitative GIS, and Snizek et al. (2013) for map matching). This yielded a dataset in which each row represents one observation (the rating given by one participant to one road section)**;** this dataset was then imported into the statistical software package SPSS (version 21) for analysis. The perceived risk rating is the response of interest and is a qualitative variable with values *Green, Amber, Red* in order of increasing perceived risk. Factors (qualitative/categorical input variables) and covariates (quantitative input variables) include the physical characteristics of the road section and the demographics of the individual participant. A statistical model was then developed to identify the significant factors and covariates in perceived cycling risk.

A number of features associated with the study design posed challenges for the model. Firstly, the response data are qualitative and ordinal. Secondly, as each participant rated several roads, observations for any given participant may be correlated. Thirdly, interactions between several of the variables can (as in any study) also arise. Of particular interest here are the interactions between individual-level and infrastructural variables. The presence of a significant interaction would imply that the effect of one independent variable (e.g. an infrastructural characteristic) on perceived risk, which is a dependent variable, differs according to a second independent variable (e.g. a characteristic of the cyclist). Also some variables can seriously mask the effect of others (e.g. when present, multicollinearity may have such a masking or other adverse effect) and it was considered appropriate to exclude certain variables (e.g. fitness) from the analysis. Bearing in mind the design and goals of the study, it was decided to employ logistic regression and to adjust the technique for the above mentioned possibility of correlations between participants' ratings and allow interactions between input variables. A Generalised Linear Mixed model was applied to investigate multi-category responses that could accommodate the within-subject correlation through random effects (McCullogh et al., 2008). Interaction terms were introduced for all two-way interactions and then excluded on the basis of lack of significance at the 5% level.

Red (dangerous) was chosen, arbitrarily, as the reference category for the response variable, Rating. Following SPSS's mixed model analysis for multinomial regression, the (multinomial) logistic model employed models:

$$\ln\left(\frac{\text{probability that a random person will respond } \mathit{Green} \text{ or } \mathit{Amber}}{\text{probability that the person will respond Red}}\right)$$

as a linear function of variables representing the factors and of the covariates, along with a random error term. The coefficient, β_i, of a covariate, X_i, (such as *age* and *road width*) represents the change in the above log-odds for a unit increase in that variable; while for a binary input variable (such as *gender* or *segregation*) the coefficient of that variable represents the expected change in the log-odds between the reference category of that variable to the other category. For the only input variable which has three categories, *cycling experience*, there were two parameters involved to represent changes from the reference to each of the other two categories (i.e. from *inexperienced* to *competent* and *highly skilled*).

For most input variables, of interest is whether a change in levels of this variable increases the log-odds (rather than changes the log-odds); that is, tests for which the alternative/research hypothesis is one-sided, e.g. are women are *more* likely than men to perceive cycling risk (as suggested by the literature) rather than simply whether there is any difference between men and women in perceiving cycling risk. For other input variables (such as *age*), a two-sided hypothesis test is applied (the p-value for a one-sided hypothesis test is half that of a two-sided test). In practice, it may be easier for interpretation purposes to exponentiate the log-odds ratios, so that then the linear function described above is replaced by an exponentiated version and one can carefully interpret the corresponding coefficients as pertaining to changes in odds rather than changes in log-odds. ~~While the analyses illustrated in this study demonstrates the potential major factors in determining perceived cycling safety, the fact that our data was not strictly generated by a probabilistic sampling design method, and the fact that variations of models that were fitted (e.g. different ways of modelling within-cyclist correlation) gave slightly different results for the significance or non-significance of certain variables, it is suggested that the hypothesis test results below may best be viewed as exploratory and as suggestions of approaches to be pursued on new data by future researchers rather than as 'definitive' statistical inferential conclusions.~~

4. Results and Discussion

4.1 Sample Characteristics

The number of survey participants was 104 and the total number of observations (i.e. perceived risk ratings) was 484, an average of 4.65 observations per participant. The average distance (subsequently included in the analysis) rated per participant was 1.95 km. Participants' ages ranged from 17 to 58 years (mean = 30.8 years; standard deviation= 10.7 years). The majority of participants were male, 60.6%, and this reflects the national cycling gender gap – in Ireland 73% cyclists are male (CSO, 2012). The sample included 36% people at work, 36% undergraduate students, 21% postgraduate students, and 6% other employment statuses. More than half of the participants cycle everyday (51%), a further 29% cycle several times per week and the remaining 20% cycle less often. 29% of cyclists in the study classified themselves as *highly skilled*, 64% as *competent* and 7% as *inexperienced*. 14% of the sample classified themselves as *very fit*, 51% as *fit*, 29% as of *average fitness* and 6% as *unfit*. The majority of participants (61%) had not been involved in a collision as a cyclist. The most common ~~motivation for~~ cycling purpose was commuting, followed by leisure, and health/fitness.

4.2 Perceived Environment

A total of 38 road sections in Galway City received a rating. Only road sections with a minimum number of ten ratings were included (as road sections will be compared with respect to a set of variables rather than compared to each other on the basis of rating, this sample size was considered satisfactory), leaving 27 road sections in the final analysis. The average length of these road sections was 419 metres and the total length of road network included in the analysis was 11 km. The River Corrib divides Galway City approximately in half, east and west. As the NUI Galway campus and the majority of residences are located west of the river, road sections at that side of the city received the majority of ratings. The most frequently rated roads were in the immediate vicinity of the university. Figure 1 shows a sample mental mapping response across a route from Salthill, a seaside suburb, to the university at the banks of the river. The start (residential roads) and end (canal towpath and university roads) are rated as *Green* (safe), while one road section is coloured *Amber* and another *Red*.

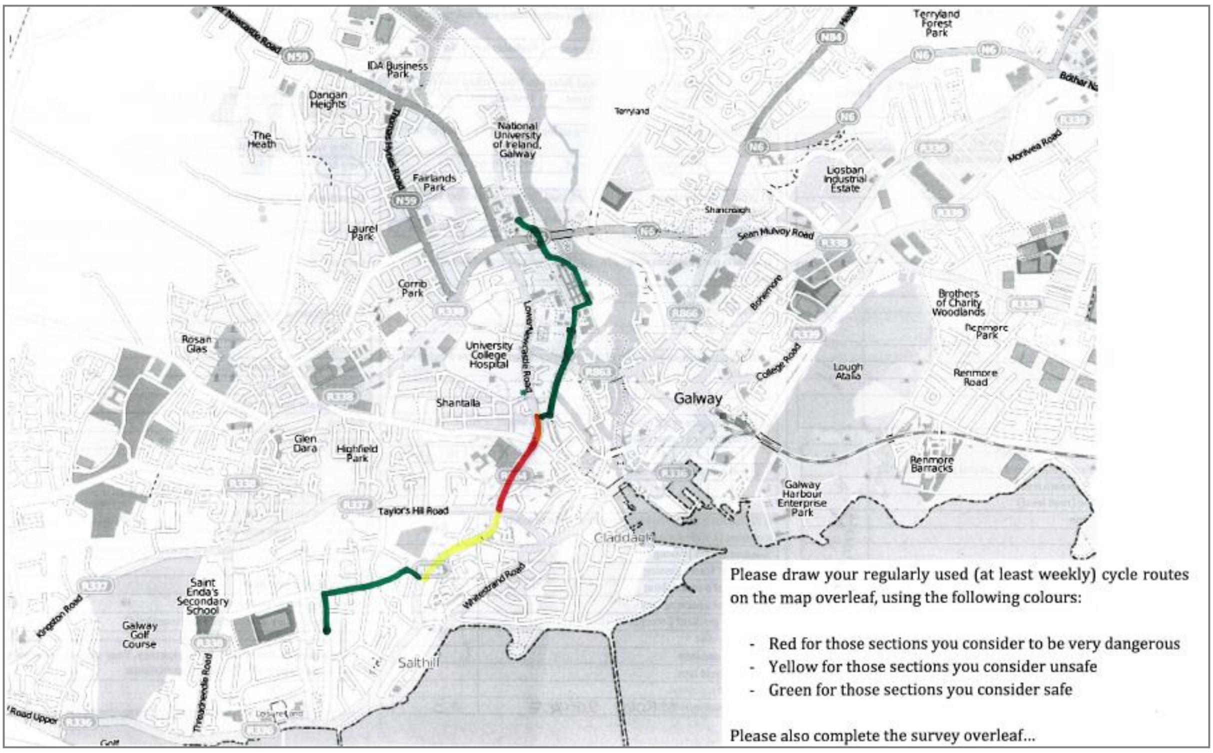

Figure 1 – Sample mental mapping response (Male, 31 years old)

Of the 484 road section ratings, almost half (48.6%) were *Green*, 29% were *Amber* and 22% were *Red*. This suggests that the majority of roads are perceived to be unsafe or very dangerous. Furthermore, ~~and~~ route choice, whereby cyclists avoid dangerous roads, ~~is likely to~~could mask the true extent of this perceived risk (Snizek et al., 2013). Of interest here is the relative influence of individual and infrastructural factors in determining this ordinal rating. For illustrative purposes in Figure 2, the three response colours have been weighted with values 1, 5 and 10 in order of increasing perceived risk. Averaging these values and forming three equally-sized categories allows a rough comparison of perceived risk across the road network.

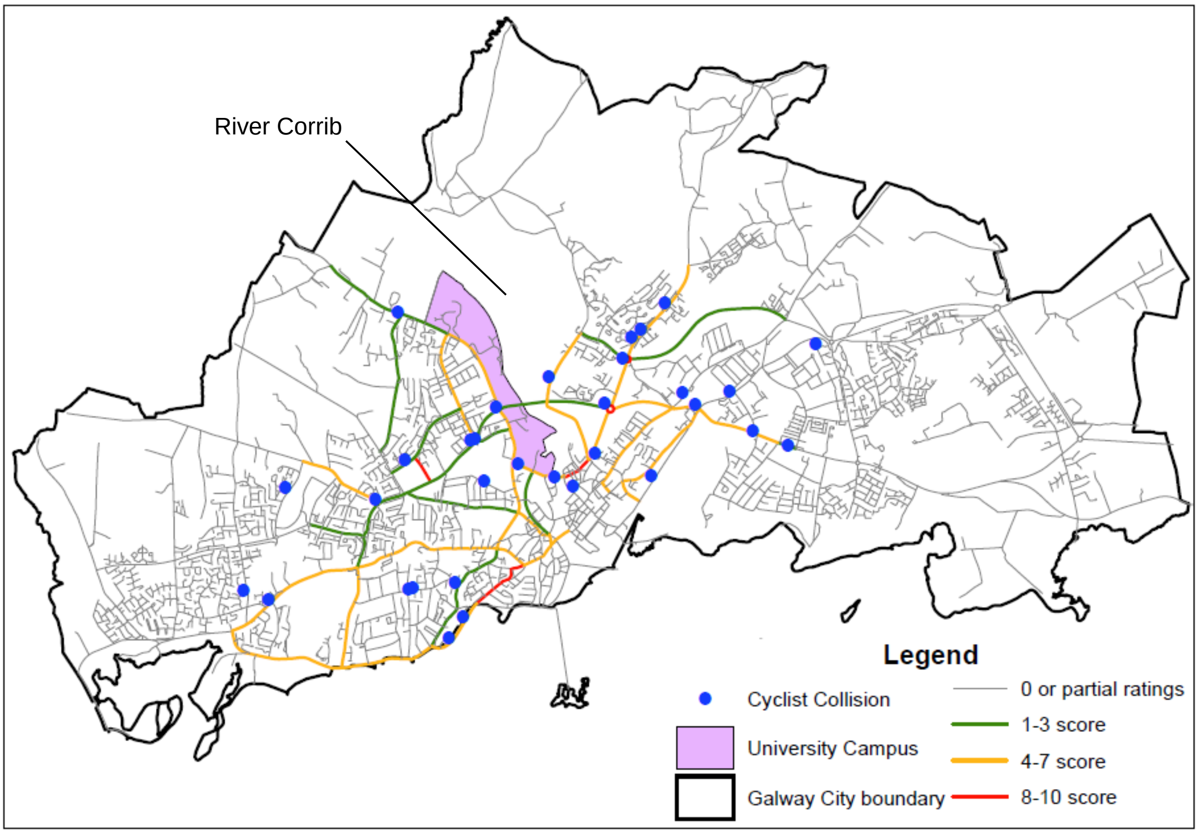

Figure 2 – Galway City road network, indicative perceived safety ratings and locations of cycling collisions

Also shown in Figure 2 are the locations of the 32 reported collisions involving cyclists in Galway City in 2005, 2006, 2007, 2008 and 2010 (RSA, 2014). There were no cyclist fatalities in Galway in this period though it is believed that cycling collisions are subject to major under-reporting (Short & Caulfield, 2014). In the absence of more reliable measures (e.g. collision intensity), this source of cycling collisions was judged to be an acceptable but basic representation of actual cycling risk. Of the 32 collisions, 23 occurred on road sections included in this study. Four collisions align with the safe category, 15 with the unsafe category and four with the very dangerous category ~~(all at roundabouts)~~. It is interesting that all of the collisions on road sections perceived as very dangerous actually took place at roundabouts, though it should be noted that the weighting system yielded just three very dangerous road sections other than roundabouts. Roundabouts were rated as very dangerous by all participants and require further research for cycling safety. Within the limitations of the arbitrary weighting of response colours and the under-reporting of cycling collisions, this suggests that some perceptions of risk align with location of actual collisions. This is envisaged as part of a complex connection between perception and reality, whereby actual risks play some role in influencing cyclists' risk perceptions, although a linear relationship is not necessarily implied.

4.3 Physical Environment

The transport infrastructure inventory compiled the engineering and traffic characteristics of the 27 road sections covered by mental mapping. Traffic volumes ranged between 0 (canal towpath) and 14,791 vehicles per day, the proportion of HGVs between 0–4%, road lane width between 2–4 m. There were two types of segregated cycling infrastructure: raised cycle lanes and the canal towpath (Figure 3). On-street car parking is available in some areas and the number of junctions ranged from two to nine. Images of typical types of road and cycling infrastructure in Galway City are shown in Figure 3.

Figure 3 – Clockwise from top left: new raised cycle lane on main road, canal towpath, typical roundabout, and a road without cycle facilities (Google, 2015)

4.4 Stated Preferences

Participants were asked to rank nine physical factors according to their impact on cycling safety. Based on the number of 1st, 2nd and 3rd rankings, three of the major safety concerns were found to be traffic-related: the number of trucks passing, speed of traffic and number of cars passing. Infrastructure proved to be less of a concern than traffic; and cyclists consider the presence of a roundabout, the width of the road lane and the presence of an adjacent car parking lane to be the most concerning characteristics of infrastructure. Other factors expressed in qualitative responses included road condition and driver behaviour.

Following the ranking of safety concerns, participants were then asked whether they felt two types of traffic (trucks and cars) and two elements of infrastructure (roundabout and car parking) compromised their safety while cycling, gauged on a 5-point Likert scale. 59.2% agreed that the number of trucks passing compromised their cycling safety, while 54.5% agreed that the number of cars passing was a major issue. 42.6% are ~~deterred~~ concerned by the presence of a roundabout, but adjacent car parking, which can result in 'dooring', ~~deterred~~ concerned just 14.9% of participants. The maximum speed limit of a road that most participants (57%) would feel comfortable sharing with motorised traffic is less than 50 km/h, 26% said 50-60 km/h and 17% said 60-80 km/h.

Participants were asked to rank their frequency of use and preferred type of cycling infrastructure or on-road cycling positions. Figure 4 shows the results of the participants' actual riding locations and shows that reasonable numbers always cycle on-road, mostly in the secondary riding position (closer to the kerb, rather than 'taking the lane'). Some participants stated that they always cycle on the footpath, potentially indicating significant fear of interaction with traffic. Figure 4 also shows the participants' preferred cycling locations with raised cycle lanes (footpath level), road-level cycle lanes and greenways receiving the highest rankings. The disparity between this clear preference for segregated cycling infrastructure and actual levels of on-road cycling suggests a deficit of dedicated cycling infrastructure, a finding in line with Caulfield et al. (2012).

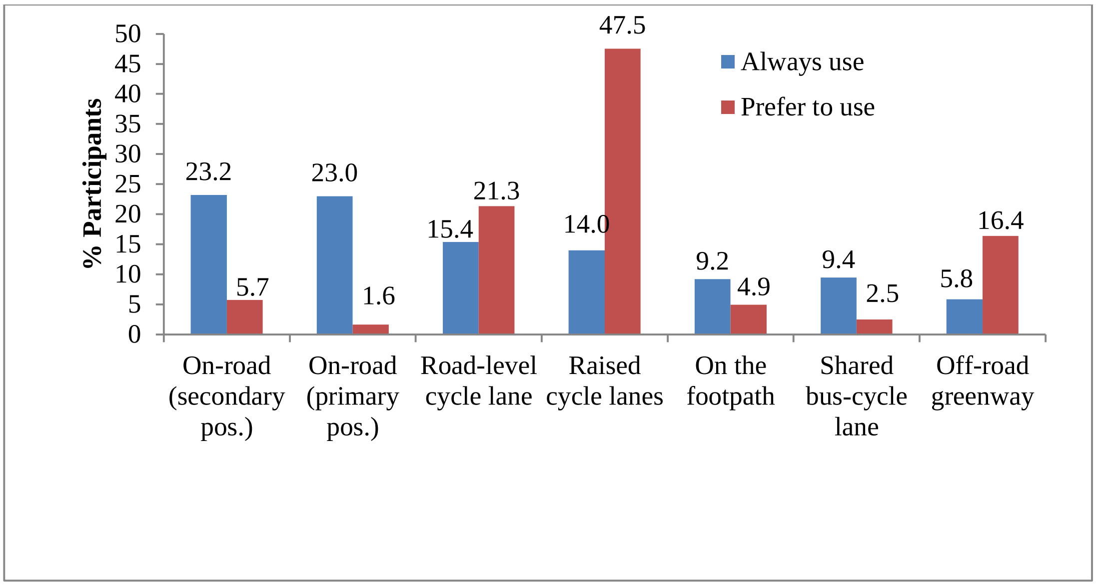

Figure 4 – Actual and preferred cycling infrastructure

Finally, the impact of participants' route choice must be considered. Cyclists may avoid roads that they identify as dangerous, e.g. those with heavy traffic. This would lead to a disparity between stated preference results and mental mapping results, as cyclists may not use the roads they perceive to be most dangerous. However, this was not determined to be significant factor in this survey as the mental mapping results show that the vast majority of participants chose the most direct route between origin and destination, most likely due to the lack of route choice in Galway City which does not have a grid pattern. Many cyclists will also temper safety concerns with time and distance delays caused by alternative routing.

4.5 Modelling Perception of Cycling Risk

A Generalised Linear Mixed Model was built in SPSS, where the Subject was the participant (using a unique participant number to identify repeated measurements) and the Target was the perceived risk rating. The Measurements were the 484 observations, including associated demographic and infrastructural data. The goal was to assess the extent to which the ordinal variable Rating relates to nine main qualitative and qualitative effects (Table 1). The qualitative variables are: *gender*, *cycling experience* [inexperienced/competent/highly skilled], *segregation* [of cycling facility; yes/no], *parking* [adjacent car parking; yes/no]. The quantitative variables are: *age*, *LV* [per 1000 light vehicles per day], *%HV* [percentage of heavy goods vehicles], *width*[of road lane in metres], and number of *junctions* (Table 1).

Table 1 – Variable information

	Variable	Category	n	Percent	Minimum	Maximum
Qualitative	*Rating*	*Green*	235	48.6		
		Amber	141	29.1		
		Red	108	22.3		
	Gender	*Female*	189	39.0		
		Male	295	61.0		
	Cycling experience	*Highly Skilled*	160	33.1		
		Competent	298	61.6		
		Inexperienced	26	5.4		
	Segregation	*Not Segregated*	324	66.9		
		Segregated	160	33.1		
	Parking	*No Parking*	230	47.5		
		Parking	254	52.5		
Quantitative	*Age* (years)		484		17	58
	LV (1000 veh)		484		0	15
	%HGV		484		0	3.9
	Width (m)		484		2	4
	Junctions (no.)		484		2	9

Figure 5a displays the percentage of participants for each category of gender. These results suggest that female participants perceived more roads as very dangerous and fewer roads as safe ~~(of course, this is not a statistical inference and has not removed the effect of other variables)~~. Figure 5b illustrates the corresponding summary for segregation, which appears to have a strong effect: dedicated cycling facilities received a larger proportion of safe ratings than road sections that involve cycling in motorised traffic. Chi-squared tests showed that there is a significant relationship between gender and rating (X^2 = 6.632, p-value = 0.036) and between segregation and rating (X^2 = 48.033, p-value = 0.000) (of course, these tests have not removed the effect of other variables). Both of these observations were also suggested by the literature and the potential interaction of individual and infrastructural variables is also of interest. For example, female participants rated a greater proportion of segregated infrastructure than their male counterparts – potentially as they are more likely choose a route on segregated infrastructure – as did older people and inexperienced cyclists.

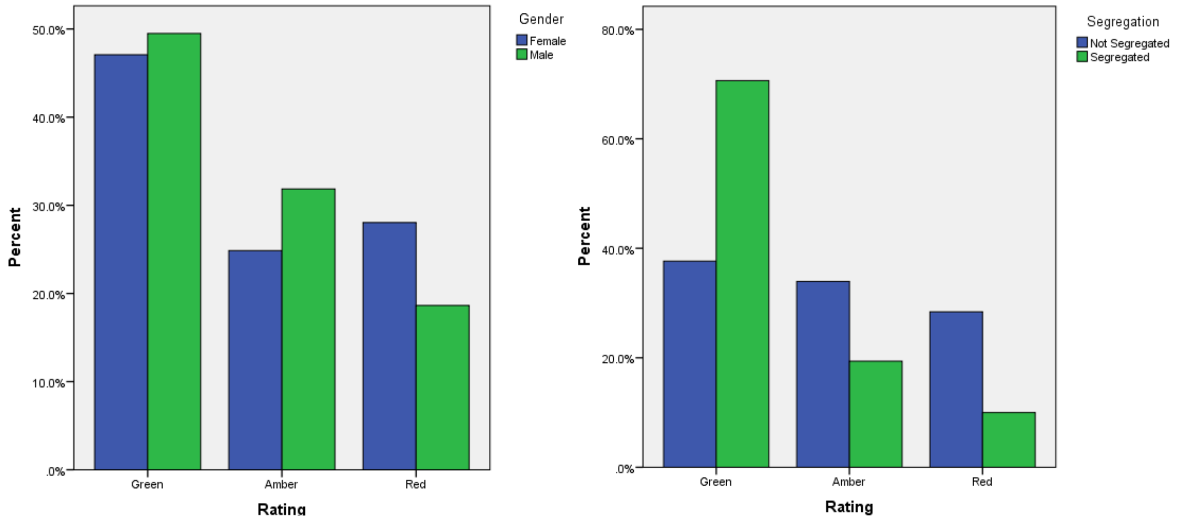

Figure 5 – Rating plotted against Gender (left) and Segregation (right)

To account for interactions between pairs of variables, all two-way interaction terms were initially included in the analysis and then systematically dropped according to their effect on the significance of main effects. Some variables have the potential to mask the effect of others and it was deemed necessary to exclude these. Fitness, for example, was dropped at an early stage of the analysis as it was found to be highly correlated with, and masking the effect of, Cycling Experience; this was also the case with Years Living in Galway and Age. Random Effects were included to account for within-subject correlations. The fitted Generalized Linear Mixed Model components are shown in Table 2. In this table, each coefficient, $\hat{\beta}$, estimates the change in the log-odds of *Green* or *Amber* relative to *Red* for a unit increase in a quantitative variable (units are denoted in parenthesis for quantitative variables) and as the change in the log-odds between the reference and the other category (or other categories) for qualitative variables. The exponentiated log-odds ratio, Exp($\hat{\beta}$), then represents changes in odds; the 95% confidence interval for the true underlying odds, Exp($\hat{\beta}$), is also shown in Table 2. Significance is implied by the magnitude of the p-value, displayed in Table 2 for two-sided hypothesis tests and is halved for cases where the alternative hypothesis is one-sided.

Table 2 – ~~Generalized Linear Mixed Model output~~Individual and infrastructural effects on perceived cycling risk

Ref=Red	$\hat{\beta}$	**Exp($\hat{\beta}$)**	**95% CI for Exp(β)**		**p-value**
			Lower	**Upper**	
Individual characteristics					
Age (years)	0.022	1.024	0.984	1.066	0.240
Gender [ref=*Male*]					
Female	1.526*	4.601	1.336	15.847	0.008
Cycling Experience [ref=*Inexperienced*]					
Highly Skilled	-1.563*	0.210	0.045	0.982	0.024
Competent	-1.694*	0.184	0.043	0.787	0.012
Infrastructural characteristics					
LV (1000 vehicles)	0.176**	1.192	1.076	1.321	0.001
HV (percent)	0.304	1.355	0.903	2.035	0.142
Width (m)	-0.977*	0.377	0.153	0.929	0.034
Junctions (number)	0.006	1.006	0.873	1.159	0.932
Parking	-0.521	0.594	0.266	1.325	0.203
Segregation	-2.993**	0.050	0.009	0.269	0.001
Interactions					
Age*[Segregation]	0.070*	1.072	1.029	1.118	0.001
%HV*[Gender = *Female*]	-0.500*	0.607	0.379	0.971	0.037

*Significant at the 5% level; **Significant at the 1% level

Individual characteristics

The coefficient for *gender* in the fitted model in Table 2 is $\hat{\beta}$ = 1.526 and the corresponding exponentiated value is exp($\hat{\beta}$) = 4.6. This means that the estimated log odds of choosing Red would increase by 1.526 for a female relative to a male (or equivalently, the estimated odds of belonging to Red relative to the reference value Green or Amber is for a female 4.6 times larger than its value for a male), when the other input variables are held constant. In other words, female respondents are significantly more likely to rate a road section as dangerous than are their male counterparts.[1] Turning to cycling experience, being a highly skilled or competent cyclist decreased the odds of perceiving risk by a factor of 0.18 (p-value = 0.024) and 0.21 (p-value = 0.012), respectively, compared to inexperienced cyclists. Significant interactions were found between *age* and *segregation* and between *gender* and *%HV*. These interactions confirm the hypothesis that the effect of some infrastructural variables differs with individual characteristics, but complicate the interpretation of the main effects. These results regarding gender and cycling experience confirm the findings of several other studies (Lawson et al., 2013; Black & Street, 2014; Ma et al., 2014; Bill et al., 2015; Dill et al., 2015). Future transport policymakers and planners should thus consider the roles of gender and the lack of cycling experience in the promotion of cycling.

Infrastructural characteristics

Of the six infrastructural variables, the number of cars (*LV*), *width* of the road lane, and cycling *segregation* were significant. The odds of rating a road section as dangerous decreased with *width* by a factor of 0.38 (p-value=0.01) for each additional metre. The number of cars passing increased the odds of perceptions risk by a factor of 1.2 (p-value <0.005) for each 1000 vehicles. Segregation had a particularly strong effect (Exp($\hat{\beta}$) = 19.9, p-value <0.005): the presence of a segregated cycling facility significantly increased perceptions of safety. These findings confirm existing research on cyclists' preferences for segregated infrastructure (Caulfield et al., 2012; Lawson et al., 2013) as well as policy and advocacy for reduced motorised traffic volumes and increased overtaking distances~~road space for cycling~~. However,

[1]When β is the corresponding true log odds, consider testing the null hypothesis $H_0: \beta = 0$ versus the (one-sided) alternative hypothesis $H_1: \beta > 0$, or equivalently testing the alternatives $H_0: \exp(\beta) = 1$ versus $H_1: \exp(\beta) > 1$, the p-value associated with the estimate is 0.008.

it is important to note that additional road lane width is unlikely to yield benefits for cycling safety as motorists typically adapt their behaviour to these conditions by increasing speed (cf. Lewis-Evans & Charlton (2006)).

Choice of model

The Generalized Linear Mixed Model (GLMM) correctly predicted 92% of Green (safe) responses and the overall percentage correctly predicted was 67%. Two other models were developed, namely multinomial logistic and ordinal logistic. Both of these models gave the same results in terms of significance of the various factors and covariates but differed from the mixed model multinomial logistic analysis in that *segregation* and the interaction between *%HV* and *gender* each lost its significance. It is interesting to note that the mixed model employed, a multinomial logistic, has allowed for possible correlation between observations on the same person, whereas the (non-mixed) multinomial and ordinal logistic models assume independence of all response observations. Future research could explore which model is more appropriate for the analysis of data from this study design.

While the analyses illustrated in this study demonstrates the potential major factors in determining perceived cycling safety, the fact that ~~our~~the data w~~as~~ere not strictly generated by a probabilistic sampling design method, and the fact that variations of models that were fitted (e.g. different ways of modelling within-cyclist correlation) gave slightly different results for the significance or non-significance of certain variables, it is suggested that the ~~hypothesis test~~ results ~~below~~above may best be viewed as exploratory and as suggestions of approaches to be pursued on new data by future researchers rather than as ‘definitive’ statistical inferential conclusions. Overall, it is envisaged that the innovative methodology developed in this paper has opened up a fruitful avenue for further mixed-method cycling safety research.

5. Conclusions

Perceived cycling risk has the potential to overshadow objective cycling risk as the major barrier to increasing uptake of cycling. Perceptions of cycling have received substantial academic attention over recent years; however, this work has focused on infrastructural determinants of perceived risk and rarely considers the characteristics of the cyclist. This study draws on attitude and behaviour theory to argue that cycling perceptions exist within a broader model of attitudes, social norms and habits (Heinen et al., 2010) that need to be understood and that new quantitative and qualitative methods are required to explore perceptions of risk. The paper presents mental mapping, a stated-preference survey and a transport infrastructure inventory to unpack perceptions of cycling risk and to make visible both overlaps and discrepancies between perceived and actual characteristics of the physical environment. While the more 'traditional' self-reported survey uncovered significant data related to perceptions of cycling risk, we argue that the data derived from the mental mapping approach has the potential to provide a more specific, placed-based assessment of these risks.

Upon critical reflection, the resulting maps display a snapshot of the geographical distribution of selected elements but exclude cyclist's in-depth cycling knowledge and experiences. Further work is needed to include these qualitative aspects in analyses and debates regarding perceived and actual cycling safety.

Participants' mental maps (n=104) delivered rich perceived safety data (n=484) and initial comparison with locations of cycling collisions showed alignment between perception and actual conditions, particularly relating to danger at roundabouts. Attributing individual and infrastructural characteristics to each observation, a Generalized Linear Mixed Model subsequently identified segregated infrastructure, road width and traffic volume as well as gender and cycling experience as significant. These results confirm previous research on participants' stated preferences and suggest interactions between the characteristics of the cyclist and infrastructural conditions in the perception of cycling risk. Future data collection could consider randomly-selected samples and more controlled physical environments to better understand these interactions.

While the size and nature of the sample does not allow for inferences about the wider population of cyclists, the findings nevertheless confirm observations made in cycling safety documents and contributions to cycling policy by cycling campaigners and lobby groups in low-cycling countries such as Ireland and the UK. Regarding cycling in traffic, these include calls for reductions in traffic speeds and volumes, as well as for changes to legislation, such as an increase in overtaking clearance distance to 1.5 m. This study also contributes to the integration-segregation debate by demonstrating the importance of segregation for reduction in perceived risk (cf. Parkin et al., 2007a; 2007b). Gaps between participants' stated preferences and actual cycling behaviour suggest a segregated cycling infrastructural deficit in the city under study, whereby most would prefer to cycle in cycle lanes, yet in practice cycle on road in traffic. Cyclists are a heterogeneous group however and characteristics such as gender and cycling experience influence risk perceptions and infrastructure preferences. Segregated infrastructure may well bring safety benefits for large sections of the population, but space restrictions, indirect routes and junction requirements mean that sharing the road with motorised traffic remains cyclists' primary means of negotiating urban areas. A combination of carefully-designed dedicated-space for cycling and making roads safer for cycling, for example by reducing traffic speeds and volumes, is recommended for improving safety perceptions among current and future cyclists.

Moving beyond a focus on infrastructural provision, the findings presented in this paper have significant implications for future cycling policy. As previous research reveals, misconceptions among different groups of road users continue to negatively affect the safety of vulnerable groups and remain a source of tension. The Irish government's target for 10% cycling modal share by 2020 requires a serious commitment to changing current attitudes and improving interactions between motorised vehicles and cyclists. National policy initiatives could be designed to both dispel prevailing perceptions of risks and raise awareness of the vulnerability of non-motorised road users. Furthermore, interventions could be targeted at those user groups, for example women, which are particularly sensitive to perceptions of cycling risk (cf. Garard et al. (2012)) as part of broader policy of dismantling the ‘fear of cycling’.

The mixed method used in this study is a reflection of the interdisciplinary nature of the project team, drawn from civil engineering, sociology, geography and statistics. There is clearly potential to further develop the mapping and matching method as well as other mixed-method approaches in transport studies in the future. Indeed, there is a dearth of research exploring how transport brings individuals into cognitive and physical contact with their built environments (Mondshein et al., 2013), and this study has shown that mental mapping has latent potential as a research tool in this respect. Building on the success of this method, further research is recommended on bicycle suitability measures and online mapping tools. Engaging cyclists and the general public through GPS-based mobile applications and the crowd-sourcing of data, including elements of mental mapping, can further unpack perceptions of cycling risk and feed into ‘soft’ and ‘hard’ cycling policy responses.

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References

Ajzen, I. (1991).The Theory of Planned Behavior. *Organizational Performance and Human Decision Processes*, 50, pp.79–211.

Aldred, R. and Woodcock, J. (2015). Reframing safety: an analysis of perceptions of cycle safety clothing. *Transport Policy*, 42, pp.103-122.

Austin, M.A., Furr, A.L. and Spine, M. (2002). The effects of neighbourhood conditions on perceptions of safety. *Journal of Criminal Justice*, 30, pp.417-427.

Bamberg, S. (2012). Understanding and promoting bicycle use – insights from psychological research. *Cycling and Sustainability*, pp.219-246.

Bill, E., Rowe, D. and Ferguson, N. (2015). Does experience affect perceived risk of cycling hazards? Scottish Transport Applications and Research (STAR) Conference. Glasgow, UK. 20th May.

Black, P. and Street, E. (2014). The power of perceptions: exploring the role of urban design in cycling behaviours and healthy ageing. *Transportation Research Procedia*, 4, pp.68-79.

Boschmann, E.E. and Cubben, E. (2014). Sketch maps and qualitative GIS: using cartographies of individual spatial narratives in geographic research. *The Professional Geographer*, 66(2), pp.236-248.

Brown, G. and Raymond, C. (2007). The relationship between place attachment and landscape values: towards mapping place attachment. *Applied Geography*, 27, pp. 89–111.

Carver, A., Timperio, A. and Hesketh, K. and Crawford, D. (2010).Are children and adolescents less active if parents restrict their physical activity and active transport due to perceived risk? *Social Science & Medicine*, 70, pp.1799-1805.

Cho, G., Rodriguez, D.A. and Khattak, A.J. (2009).The role of the built environment in explaining relationships between perceived and actual pedestrian and bicyclist safety. *Accident Analysis and Prevention*, 41, pp.692-702.

Chow, S.L. (2002). Issues in Statistic Inference. *History and Philosophy of Psychology Bulletin*, 14(1), pp.30-41.

Central Statistics Office (CSO) (2012).*Results of Census 2011 – Profile 10 Door to door – Commuting in Ireland.* Cork, Ireland.

Davies, A, Fahy, F. and Rau, H. (2014).Challenging Consumption. In Davies, A.R., Fahy, F. and Rau, H. (Eds.), *Challenging Consumption: pathways to a more sustainable future*. London: Routledge, pp.3-19.

Deegan, B. (2015). Mapping everyday cycling in London. In: P. Cox (Ed.), *Cycling Cultures*, Chester: University of Chester, pp.106-129.

Department of Transport, Tourism and Sport (DTTAS) (2009a). *Smarter Travel*. Dublin, Ireland.

Department of Transport, Tourism and Sport (DTTAS) (2009b). *National Cycle Policy Framework*. Dublin, Ireland.

Dill, J., Goddard, T., Monsere, C.M. and McNeil, N. (2015). Can protected bike lanes help close the gender gap in cycling? Lessons from five cities. Annual Conference of the Transportation Research Board (TRB). Washington DC, USA. 11-15th January.

Doorley, R., Pakrashi, V., Byrne, E., Comerford, S., Ghosh, B. and Groeger, J.A. (2015).Analysis of heart rate variability amongst cyclists under perceived variations of risk exposure. *Transport Research Part F*, 28, pp.40-54.

Elias, W. and Shiftan, Y. (2012). The influence of individual's risk perception and attitudes on travel behaviour. *Transportation Research Part A*, 46, pp.1241-1251.

European Road Safety Observatory (ERSO) (2012). *Traffic safety basic facts 2012 – cyclists.* European Commission, Brussels, Belgium.

Fahy, F. and Ó Cinnéide, M. (2009). Re-Mapping the urban landscape: community mapping – an attractive prospect for sustainability? *Area*, 41, pp.167-175.

Fernández-Heredia, Á., Jara-Díaz, S. and Monzón, A. (2014). Modelling bicycle use intention: the role of perceptions. *Transportation*, published online.

Fishbein, M. and Ajzen, I. (1975). *Belief, Attitude, Intention, and Behavior: An Introduction to Theory and Research*. Addison-Wesley, Reading, UK.

Galway City Council (2013). *Galway traffic counts 2012: Manual classified junction counts*. Conducted by Abacus Transportation Surveys for Galway City Council.

Galway City Council (2012). *Walking and cycling strategy.* Galway, Ireland.

Garrard, J., Rose, G. and Lo, S. K. (2008). Promoting transportation cycling for women: the role of bicycle infrastructure. *Preventive Medicine*, 46(1), pp.55-59.

Garrard, J., Handy, S, and Dill, J. (2012). Women and Cycling. In: J. Pucher and R. Buehler, (Eds.) *City Cycling*, Cambridge, MA: MIT Press, pp. 211-234

Gehlert, T., Dziekan, K., and Garling, T.(2013).Psychology of sustainable travel behaviour. *Transportation Research Part A*, 48, pp.19-24.

Google (2015). *Google Maps.* Available at: maps.google.com [Accessed 1st July 2015].

Gould, P. and White, R. (1993). *Mental maps* (3rd ed.). Boston; London: Allen & Unwin.

Gregory, D. (2009). *The Dictionary of Human Geography Wiley-Blackwell*, Oxford (5th Edition).

Harkey, D.L., Reinfurt, D.W. and Knuiman, M. (1998). Development of the Bicycle Compatibility Index. *Transportation Research Record*, 1636, pp.13-20.

Heinen, E., Van Wee, B. and Maat, K. (2010). Commuting by bicycle: an overview of the literature. *Transport Reviews*, 30(1), pp.59-96.

Heisserer, B. (2013). Curbing the Consumption of Distance? A practice-theoretical investigation of an employer-based mobility management initiative to promote more sustainable commuting. NUI, Galway: Unpublished PhD thesis.

Horton, D. (2007). Fear of cycling. *Cycling and Society*, pp.133-152.

Hunt, J.D. and Abraham, J.E. (2007). Influences on Bicycle Use. *Transportation*, 34, pp.453-470.

Jacobsen, P.L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury Prevention*, 9(3), pp.205-209.

Jensen, S.U., Rosenkilde, C. and Jensen, N. (2007). *Road safety and perceived risk of cycle facilities in Copenhagen.* Presentation to AGM of European Cyclists Federation.

Johnston, R .J., Gregory, D., Pratt, G. and Watts, M. (eds.) (1986). *The Dictionary of Human Geography*. Oxford (Blackwell) 2nd edition.

Kazig, R. and Popp, M. (2010). Unterwegs in fremden Umgebungen: Ein praxeologischer Zugang zum „wayfinding" von Fußgängern. *Raumforschung und Raumordnung*, 69(1), 3-15.

Lawson, A.R., Pakrashi, V., Ghosh, B. and Szeto, W.Y. (2013). Perception of safety of cyclists in Dublin City. *Accident Analysis and Prevention*, 50, pp.499-511.

Lewis-Evans, B., & Charlton, S. G. (2006). Explicit and implicit processes in behavioural adaptation to road width. *Accident Analysis & Prevention*, 38(3), pp.610-617.

Liang, K-Y.and Zeger, S.L. (1986). Longitudinal data analysis using generalized linear models. *Biometrika*, 73(1), pp.13-22.

Loidl, M. (2014). How GIS can help to promote safe cycling. *Proceedings of the 28thEnviroInfo Conference*. Olderburg, Germany. 10-12th September.

Lowry, M., Callister, D., Gresham, M. and Moore, B. (2012). Assessment of Communitywide Bikeability with Bicycle Level of Service. *Transportation Research Record*, 2314, pp.41-48.

Lydon, M. (2003). Community mapping: the recovery (and discovery) of our common ground. *Geomatica*, 57, pp.131-44.

Lynch, K. (1960). *The Image of the City*. Cambridge MA: MIT Press.

Ma, L., Dill, J. and Mohr, C. (2014). The objective versus the perceived environment: what matters for bicycling? *Transportation*, 41(6), pp.1135-1152.

Manton, R. and Clifford, E. (2012). A study of travel patterns to NUI Galway: lessons for Smarter Travel in Universities. Irish Transport Research Network (ITRN) Conference. University of Ulster, Jordanstown, UK. 29-30th August.

McCulloch, C. E.andNeuhaus, J. M. (2003). *Generalized linear mixed models*. John Wiley & Sons, Ltd.

Met Éireann (2015). *Monthly data for Athenry weather station.* Irish Meteorological Service Online. Available at: http://www.met.ie/climate/monthly-data.asp?Num=1875 (accessed 2nd July 2015).

Møller, M. and Hels, T. (2008).Cyclists' perception of risk in roundabouts. *Accident Analysis and Prevention*, 40, pp.1055–1062.

Mondshein, A., Blumenburg, E. and Taylor, B. (2013).Going mental: everyday travel and the cognitive map. *Access*, 43, pp.2-7.

Mondshein, A., Blumenburg, E. and Taylor, B. (2010).Accessibility and cognition: the effect of transport mode on spatial knowledge. *Urban Studies*, 47(4), pp.845-866.

Nelson, T.A., Denouden, T., Jestico, B., Laberee, K. and Winters, M. (2015). BikeMaps.org: a global tool for collision and near miss mapping. *Frontiers in Public Health*, 3(53), pp.1-8.

Noland, R.B. (1995). Perceived risk and modal choice: risk compensation in transportation systems. *Accident Analysis and Prevention*, 27(4), pp.503-521.

Nye, M. and Hargreaves, T. (2009).Exploring the social dynamics of proenvironmental behaviour change. *Journal of Industrial Ecology*, 14**,** pp.137-149.

Parkin, J., Wardman, M. and Page, M. (2007a).Models of perceived cycling risk and route acceptability. *Accident Analysis and Prevention*, 39, pp.364-371.

Parkin, J., Ryley, T. and Jones, T. (2007b). Barriers to cycling: an exploration of quantitative analyses. *Cycling and Society*, pp.67-82.

Parkin, J. and Coward, A. (2009).Comparison of methods of assessing cycle routes. *Proceedings of the ICE – Municipal Engineer*, 162, pp.7-14.

Prendergast, P. and Rybaczuk, K. (2005) *Using visualisation techniques in planning to improve collaborative governance in Ireland*. Paper presented at CORP 2005, Vienna.

Pucher, J. and Dijkstra, L. (2000). Making walking and cycling safer: lessons from Europe. *Transportation Quarterly*, 54(3), pp.25-50.

Raidió Teilifís Éireann (RTÉ) (2015). 'The growing war between cyclists and motorists, what's happening on our streets?'.Broadcast 26th May.

Rengert G.F. and Pelfrey, W.V. (1997). Cognitive Mapping of the City Center: Comparative Perceptions of Dangerous Places, In: David Weisburd and Tom McEwen, eds. (1997) *Crime Mapping and Crime Prevention*, pp.193-217, Willow Tree Press, New York.

Road Safety Authority (RSA) (2014). Provisional Review of Road Crashes 2014. Ballina, Co. Mayo, Ireland.

Sanders, R. (2015).Perceived traffic risk for cyclists: the impact of near miss and collision experiences. *Accident Analysis & Prevention*, 75, pp. 26-34.

Sener, I. N., Eluru, N. and Bhat, C.R. (2009).An analysis of bicycle route choice preferences in Texas, US. *Transportation*, 36(5), pp.511-539.

Short, J. and Caulfield, B. (2014).The safety challenge of increased cycling. *Transport Policy*, 33, pp.154-165.

Smith, T.M.F. (1983). 'On the validity of inferences from non-random samples'. *J. R. Statist. Soc. A*, 146(4), pp.394-403.

Snizek, B., Nielsen, T.A.S. and Skov-Petersen, H. (2013).Mapping bicyclists' experiences in Copenhagen. *Journal of Transport Geography*, 30, pp.227-233.

Soini, K. (2001). Exploring human dimensions of multifunctional landscapes through mapping and map making. *Landscape and Urban Planning*,57, pp.225-239.

Spears, S., Houston, D. and Boarnet, M.G. (2013).Illuminating the unseen in transit use: a framework for examining the effect of attitudes and perceptions on travel behaviour. *Transportation Research Part A*, 58, pp.40-53.

Sprinkle Consulting (2007). *Bicycle level of service, applied model.* Sprinkle Consulting Inc., Tampa, Florida, USA.

Thogerson, J. (2006). Understanding repetitive travel mode choices in a stable context: a panel study approach. *Transportation Research Part A*, 40, pp.621-638.

Timperio, A, Crawford, D., Telford, A. and Salmon, J. (2004). Perceptions about the local neighbourhood and walking and cycling among children. *Preventive Medicine*, 38, pp.39-47.

The Guardian (2013).*Over 1,000 cyclists stage die-in protest outside Transport for London HQ*. Available at: http://www.theguardian.com/environment/bike-blog/2013/dec/01/stop-killing-cyclists-die-in-tfl-protest [Accessed 1st July 2015].

UK Department for Transport (UK DfT) (2014).*British Social Attitudes Survey 2013: Public attitudes towards transport.* London, UK.

Whannell, P., Whannell, R. and White R. (2012). Tertiary student attitudes to bicycle commuting in a regional Australia university. *International Journal of Sustainability in Higher Education*,13, pp.34-45.

Winters, M., Babul, S., Becker, H.J.E.H., Brubacher, J.R., Chipman, M., Cripton, P.,Cusimano, M.D., Friedman, S.M., Harris, M.A., Hunte, G., Monro, M., Reynolds, C.C.O., Shen, H. and Teschke, K. (2012). Safe cycling: how do risk perceptions compare with observed risk?. *Can J Public Health*, 103(9), S42-S47.

Wooliscroft, B. and Ganglmair-Wooliscroft, A. (2014). Improving conditions for potential New Zealand cyclists: an application of conjoint analysis. *Transportation Research Part A: Policy and Practice*, 69, pp.11-19.

Zeile, P., Resch, B., Dörrzapf, L., Exner, J. P., Sagl, G., Summa, A. and Sudmanns, M. (2015).Urban Emotions –tools of integrating people's perception into urban planning. Proceedings REAL CORP 2015 Tagungsband. Ghent, Belgium. 5-7th May.