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**ELECTROPHYSIOLOGICAL ACTIVITY DURING STIMULUS CLASS
FORMATION**

Thesis submitted for the Degree of Doctor of Philosophy

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Abstract

The current project attempted to isolate patterns of electrophysiological activity that correlate with stimulus equivalence by examining the frequency spectra of simultaneous electroencephalographic (EEG) activity. This is the first recorded attempt to isolate the frequency correlates of stimulus equivalence.

Six experiments were conducted. Experiment 1.1 employed a linear matching-to-sample equivalence training protocol with easily recognizable (iconic) stimuli to train 6 3-member equivalence classes. Experiment 1.2 employed an identical protocol with the exception of the use of abstract images instead of iconic stimuli. In both experiments, approximately half of the participants displayed equivalence. EEG results from Study 1 were inconclusive but did indicate that delta activity in the midline and posterior regions was correlated to activity during conditional discrimination training and equivalence as well as overall alpha activity, when compared to baseline. The protocol was amended for Experiments 2.1 and 2.2.

Participants were exposed to a set number of training and extinction trials rather than a preset mastery criterion. Second, the number of trials presented during equivalence testing was increased. Participants which failed to display equivalence were not re-exposed to the protocol. Experiment 2.1 employed a linear matching-to-sample training to train 3 3-member equivalence classes using iconic stimuli while Experiment 2.2 employed abstract stimuli. As in Experiment 1.1, approximately half of the participants in Experiment 2.1 displayed equivalence, but only one participant in Experiment 2.2 displayed equivalence. Experiment 2.1 in Study 2 replicated the baseline effects in the delta frequency but not in the alpha frequency. Differences were found between task stages in the Mid- and Right-Frontal regions in the gamma range, as well as baseline differences in the posterior regions. In Experiments 3.1 and 3.2, was shortened further. Experiment 3.1 had a slightly lower yield than Experiments 1.1 and 2.1, and only one participant in Experiment 3.2 displayed equivalence.

Differences in EEG power between baseline and training and testing stages were observed for all frequency bands, but no differences were found between different training and testing stages. Chapter 5 reports two sets of additional analyses. First, participants from Experiments 2.1 and 3.1 were pooled into one dataset to compare baseline differences in EEG activity. Significant differences between high and low performing participants in the gamma range at the Mid-Frontal, Mid-Central, Right-Central and Right-Posterior locations with high performing participants displaying higher gamma activity during baseline than low performing participants. Second, participants from Experiments 2.1, 2.2, 3.1 and 3.2 were pooled and their EEG activity during conditional discrimination training was compared based on stimulus types. Delta activity was more pronounced at the Mid-Posterior region in participants exposed to iconic stimuli than those exposed to abstract stimuli. These experiments provide evidence that gamma activity during baseline may predict subsequent performance on a stimulus equivalence task, and that gamma activity in the posterior regions is more reactive to abstract stimuli than iconic stimuli. The current results indicate that any possible future physiological interventions to increase accuracy on equivalence tests should focus on posterior gamma activity.

Fyrir Leif afa, sem kenndi mér að meta rökræður, og Halla afa sem alltaf hafði svörin á
reiðum höndum

For grandpa Leif, who taught me the joy of debate, and grandpa Halli who always had the
answers

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'Bare and exposed is one, without a friend by his side'

~ The Story of Burnt Njal

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List of Abbreviations

ABE: AB Extinction

ABT: AB Training

AD/HD: Attention Deficit/Hyperactivity Disorder

ANOVA: Analysis of Variance

BCE: BC Extinction

BCT: BC Training

BDI: Becks Depression Inventory

BOLD: Blood Oxygen Level Dependence

DLPFC: Dorsolateral Pre-Frontal Cortex

EEG: Electroencephalograph

ERP: Event-Related Potential

FFT: Fast Fourier Transform

fMRI: Functional Magnetic Resonance Imaging

ISI: Inter Stimulus Interval

ITI: Inter Trial Interval

LC: Left-Central

LF: Left-Frontal

LP: Left-Posterior

MC: Mid-Central

MF: Mid-Frontal

MTS: Matching to Sample

MP: Mid-Posterior

RC: Right-Posterior

RF: Right-Frontal

RP: Right-Posterior

tDCS: Transcranial Direct Current Stimulation

TMS: Transcranial Magnetic Stimulation

VLPFC: Ventrolateral Pre-Frontal Cortex

VI: Verbal Imagery

WA: Wholistic Analytic

WAIS – III: Wchsler Adult Intelligence Scale – Third Edition

WCST: Wisconsin Card Sorting Test

WISC – III – UK: Wechsler Intelligence Scale for Children

μV^2 : Microvolt Squared

Chapter 1: Introduction

Stimulus Equivalence

Stimulus equivalence describes a behavioural outcome in which individuals respond to different stimuli as if they are the same, without being directly trained to do so and without any consistent physical or perceptual similarity amongst those stimuli being necessary.

Stimulus equivalence is typically observed after a series of conditional discriminations (Critchfield & Fienup, 2008). In one example of such training, a participant might be taught to choose one particular 'B' arbitrary stimulus comparison from amongst an array in the presence of each of a number of arbitrary 'A' stimulus samples. Subsequently, they might be trained to choose 'C' stimulus comparisons for each of a number of 'B' stimulus samples.

After this conditional discrimination training, the following untrained (or derived) responses might be observed: reflexivity (identity matching, choosing A in the presence of A), transitivity (choosing C in the presence of A), symmetry (choosing A in the presence of B or B in the presence of C) and finally combined symmetry and transitivity, referred to as

equivalence (choosing A in the presence of C). The properties of reflexivity, transitivity and symmetry constitute the defining properties of the stimulus equivalence relation (Sidman, 1994; Galizio et al, 2001; Wirth & Chase, 2002). With stimulus equivalence, behaviour analysts were able to tackle important questions that had been confined to cognitive psychology. Most importantly, stimulus equivalence can explain how words and other symbols come to refer to non-verbal symbols (Sidman, 1994). This problem of meaning or the problem of intentionality has been deemed by philosophers of science as one of the hardest problems of psychology (see for example Flanagan, 1991; Millikan, 1993).

Additionally, stimulus equivalence can be used to understand the problem of induction or creativity. According to Sidman (1994), the problem of induction is "the derivation of general principles from particular facts or instances" p. 15.

Stimulus Equivalence and Language

Catania (1986) highlights three types of stimulus control that define language (or verbal behaviour): 1. Instructional Control, 2. Equivalence Classes and 3. Autoclitic processes. One of the differences between verbal and non-verbal behaviour is that verbal events can function ‘both as stimuli and as responses’ (Catania, 1986, p. 7). For example, when a child is taught to read and write, “spoken words [...] are trained to visual stimuli [...] and then to written symbols” (Pierce and Cheney, 2004, p. 445). In this example spoken words are responses in both cases, but it is also possible to use these words as stimuli. In the presence of a spoken word, one might for example execute a certain behaviour, such as picking up an object. This is one possible way of understanding how words acquire meaning and thus may form the behavioural basis for complex phenomena such as categorization (Galizio, Stewart & Pilgrim, 2001).

The relationship between stimulus equivalence and language has been supported by a range of experimental results. Devany, Hayes & Nelson (1986) compared three groups of children with the same mental age on a test of equivalence. The first group consisted of normally developing children, the second one of developmentally delayed children with expressive speech abilities and the last one mentally handicapped children with language deficiencies. Their results showed that the children in the first two groups displayed equivalence, but not the children in the third group. This would indicate that the ability for equivalence could be predicted by language proficiency rather than general intelligence or cognitive ability. Hayes & Bissett (1998) also found that stimulus relations can be used as a behavioural model for semantic meaning. Participants in their experiment were trained in three 3-member equivalence classes where the stimuli used were nonsense words designed to resemble real words. Next, the participants were exposed to a priming paradigm and the stimulus pairs used were the nonsense words used in the equivalence training. Participants

were shown a total of 24 pairs of equivalence class members that had previously been directly trained (8 pairs), or related via symmetry (8 pairs) or equivalence (8 pairs). For comparison, the participants were also shown 24 pairs of unrelated stimulus pairs. The results showed that the words which belonged to the same equivalence class showed a priming effect similar to those seen with semantically related words (e.g., bread-cake or tiger-cat).

O'Hora and colleagues (O'Hora, Pelaez & Barnes-Holmes, 2005; O'Hora, Pelaez, Barnes-Holmes, Rae, Robinson & Chaudhary, 2008 and Cassidy, Roche & O'Hora, 2010) have shown that equivalence responding correlates with performance on intelligence tests, specifically the verbal subtests of the Wechsler Adult Intelligence Scale Third Edition (WAIS-III). O'Hora, Pelaez & Barnes-Holmes (2005) reported a strong significant correlation between participants' performance on the WAIS-III vocabulary subtest and on performance on a complex relational task. Additionally, a smaller yet significant correlation between the arithmetic subtests and performance on complex relational tasks was also found. These results were later partly replicated and expanded when O'Hora et al. (2008) investigated the correlation between all thirteen subtests of the WAIS-III and performance on a complex relational task. The correlations between the vocabulary subtest and the relational task were confirmed, but not between the relational task and the arithmetic subtest. Additionally, performance on the perceptual organization index on the WAIS-III, as well as the Full Scale, also had a positive correlation to performance on the complex relational task. However, no correlations were found between the complex relational task and the working memory subtest of the WAIS-III (Wechsler, 1997). Cassidy, Roche & Hayes (2011) reported that interventions based on derived relational responding (DRR) had been used to increase IQ scores, as measured by the Wechsler Intelligence Scale for Children (WISC-III-UK), in 7 out of 8 participants in the study. The aforementioned studies all support the notion that stimulus equivalence is related to language and linguistic performance.

The probability of forming equivalence relations, given certain training, depends on the type of stimuli used in equivalence experiments. Stimuli that have prior function, such as familiar words, are more likely to be formed than classes that do not include such stimuli. Typically, nonsense stimuli have been used in equivalence research as they have been thought less likely to already be a part of equivalence classes than are words or easily nameable stimuli (Holth & Arntzen, 1998). However, as Holth & Arntzen point out, these nonsense words can sometimes be pronounced and could therefore participate in pre-experimental equivalence classes. Further studies provide evidence that broadly supports these claims (Arntzen, 2004; Bentall, Dickins & Fox, 1993; Holth & Arntzen, 1998). Bentall, Dickins & Fox (1993) compared the effects of stimulus types and naming on the acquisition of equivalence. In the first experiment in the study, the participants were split into three groups, and all were trained in six three-member equivalence classes, but were exposed to three different classes of stimuli. The first group was exposed to easily nameable stimuli from obvious semantic categories. The stimuli used for the second group were easily nameable stimuli that did not fall into any semantic categories. Finally, the third group was exposed to abstract stimuli. To determine whether learning occurred during testing (that is if performance improved during the equivalence stage), all three groups were tested twice and each testing stage consisted of 72 trials that tested on A-B, B-C, Symmetry, Transitivity and Equivalence relations. Participants in the first group needed significantly fewer trials to acquire the conditional discriminations than the other groups and produced the fewest errors in equivalence testing stages. The performance of the second group was substantially different from that of the first.

Participants in the second group (easily nameable, different semantic categories) needed 5 times the amount of training in the initial A-B training stage of participants in the first group, three times the number of training trials in the B-C training stage, a third more in

the third stage and approximately a quarter more training trials on the fourth and last stage. The second group also performed significantly worse than the first group in the testing stages, with approximately ten times the number of errors in the tests of derived relations in the first stage of testing and five times the number in the second testing stage. The third groups' performance during training was similar to the second groups', although significantly worse than the second group only during the first stage of testing. During the first test stage, the third group performed at a similar level as the second one, but unlike them, did not improve significantly during the second test stage.

In the second experiment, the protocol was adjusted slightly so that the sample and the comparison were not presented together as in the previous experiment. Additionally, this experiment included only two experimental groups, one in which the stimuli were pre-associated easily nameable stimuli and the other in which the stimuli were the same abstract images as in the previous experiment. The slight change in stimulus presentation did not affect the reaction times in a significant way. However, more errors were made by the abstract group in this experiment than in the previous one and the group exposed to nameable stimuli had comparable error rates as in the previous experiment. In the third and final experiment, two groups of participants were exposed to abstract stimuli using the same experimental procedure as in the previous experiments with one variation. The first group was taught to name all the stimuli in each equivalence class using a separate name (one name for each A-B-C stimulus class), and the second group were taught individual stimulus names for all 18 abstract stimuli used in the experiment. The results showed that teaching participants names for the classes resulted in fewer training trials needed and decreased their error rate during the testing stages. The differences in reaction times were not as clear, as no difference was found between the groups during the testing for A-B/B-C and Symmetry, but the group which was taught individual names had reaction times almost double those that

were taught names for the stimulus classes. Overall, the authors concluded that there are two distinct patterns of equivalence responding. The “Type 1” participants showed correct transitive and/or equivalence relations early in the testing stages. “Type 2” participants, on the other hand, needed repeated exposure to the testing stages to display transitivity and equivalence.

These results show that although it is difficult for participants to form equivalence relations using abstract or hard to name stimuli, equivalence relations can be trained using those types of stimuli. Holth & Arntzen (1998) propose that the abstract stimuli might occasion different private verbal behaviour than the easily nameable or previously categorized stimuli. These private verbal behaviours might entail more effort by the participants, and therefore a longer inter stimulus interval (ISI) might be needed when the stimuli are abstract rather than easily nameable (or iconic).

In two experiments, Holth & Arntzen (1998) further explored the role of stimulus types in the acquisition of stimulus equivalence as well as the critical variables in Delayed Emergence of stimulus equivalence. Delayed Emergence of Stimulus Equivalence was defined as “improved performance during equivalence testing” (Holth & Arntzen, 1998, p. 83). That is delayed emergence of stimulus equivalence was observed if participants initially failed stimulus equivalence and subsequently passed equivalence on subsequent training. This was observed only when testing with familiar stimuli. This delayed emergence seems to apply only to testing within a single exposure. That is, not when participants are consistently re-exposed to the experimental protocol until they display equivalence, but only their performance within a single exposure to the experimental protocol. In the first experiment, 50 participants were split into five experimental groups: 1) A, B & C stimulus classes were all Greek letters and only Equivalence was tested. 2) A & C were easily nameable pictures, but B was a Greek letter and Symmetry, Transitivity and Equivalence were all tested. 3) A & C

were pictures but B was a Greek symbol, and only Equivalence was tested. 4) A & C were Greek symbols, only Equivalence was tested. 5) A & B were Greek symbols; C was a picture, only Equivalence was tested. Holth & Arntzen used an errorless training procedure during training, similar to the one used by Bentall, Dickins & Fox (1993) which had previously found a difference in equivalence test outcomes based on abstract and iconic stimuli. However, to explore Delayed Equivalence the test stages consisted of 24 trials which were organized into two blocks of tests.

Holth & Arntzen's (1998) results showed that both the type of stimuli used and the location within the linear training were important. In the first group, only one participant displayed equivalence in the first half of the equivalence test, but three in the second half. In the second group, 9 out of 10 participants displayed transitivity and all displayed equivalence. In Group 3, 9 out of 10 participants displayed equivalence and in Group four, 9 out of the 10 participants displayed equivalence on the first half of the equivalence test and all 10 on the second half. Finally, in the fifth group, only one participant displayed equivalence on the first half of the test and an additional five participants displayed equivalence on the second equivalence test. Overall, the results seem to indicate that the type of stimulus used plays a crucial role in the formation of equivalence relations. According to Arntzen (2004), using a recognizable stimulus could make it easier for participants to 'merge' novel stimuli into an already existing stimulus class or in other ways aid in performance-enhancing private rule generation.

In Holth and Arntzen's second experiment, the same stimuli were used but the training protocol was adjusted slightly. In Group 6, the 'A' stimuli were pictures, the B & C stimuli were Greek letters. If subjects did not display equivalence, they had one of the following follow ups: a) Pictures as 'B' stimuli and Greek letters as 'A' and 'C' stimuli. b) re-exposure to the initial training and test. If equivalence was not displayed, subjects were

exposed to the a) follow up procedure. All stimuli were pictures for the seventh group. If subjects displayed equivalence, they were exposed to a new task with all Greek letters. If equivalence was not displayed, they were exposed to a task with the 'B' stimuli as pictures. Finally, for the eighth group, all stimuli were Greek letters and the follow up consisted of the 'A' and 'C' stimuli as Greek letters and the 'B' stimuli as pictures. Finally, participants were re-exposed to the first all-Greek protocol. 1 out of 10 participants in the sixth group displayed equivalence in the first half of testing, and 2 in the second half. Of the nine that did not display equivalence on the first exposure, 5 did so when pictures were used as 'B' stimuli and also when re-exposed to the task where 'A' stimuli were pictures. In the seventh group, 7 out of 10 participants displayed equivalence and an additional 2 in the second half of the test. The one remaining participant did display equivalence where the 'B' stimuli were pictures. In the follow up, where all stimuli were Greek letters, two participants displayed equivalence in the first half of testing, and an additional three in the second half. In the eighth group, only one out of the 10 participants displayed equivalence, but none in the second half. In the follow up, when 'B' stimuli were pictures, all participants displayed equivalence in both test halves. In the final condition, re-exposure to the all Greek letters, 3 out of 10 participants displayed equivalence in both test halves. As previously observed, the type of stimuli observed and the location within training were important.

To isolate any possible effect of the training and testing procedure, Arntzen (2004) replicated the Holth & Arntzen (1998) study, but used a many-to-one training procedure rather than a linear one. As in the previous experiment, an errorless training paradigm was used. The training order was as follows: 1) AB; 2) CB; 3) Mix AB & CB; 4) DB; 5) Mix AB, 6) CB & DB; 7) EB; 8) Mix AB, CB, DB & EB. As before, the equivalence tests were conducted in two subsequent blocks to test for delayed equivalence. Fifty participants were split into five experimental groups and as before responding was done via touch screen

except for the last group which responded via keyboard. When all the stimuli used in the experiment were Greek or Arabic letters (equivalent to abstract symbols according to the author), only 3 out of 10 participants displayed equivalence. If the 'A' stimulus was a picture but all other stimuli were Greek letters, all 10 participants displayed equivalence. If the last stimulus was a picture but all others were Greek letters, only 5 out of the 10 participants displayed equivalence. If the 'A' stimulus was a nonsense syllable but all others were Greek letters, four out of ten participants displayed equivalence. In the final group, the 'A' stimuli were pictures but all other stimuli were Greek letters but responding was done with a keyboard. In this group, only 4 participants displayed equivalence. According to Arntzen (2004) it seems that the critical variable might not be the type of stimuli used, but rather when that stimulus is presented to the participant. However, this might be questioned.

As Arntzen himself points out, the mode of responding could also be an important factor, as participants that responded on a touch screen performed better than those using a keyboard. This could be because as the participant moves the cursor over the screen with his or her hand, he or she observes where the cursor is and therefore "observes the S⁺ and increases the likelihood of a select relation" (p. 286). This difference could also be due to an effect from verbal behaviour, as the class names can be inconsistent with the keyboard labels, therefore interrupting the naming of the stimuli, or at least introducing another variable into the classification process. This inconsistency could even be in place when the keys on the keyboard are covered (as is common practice in many experiments) because the participants have learned the location and name of the keys and the 'key in position X' therefore serves the same function as the label for that key when the participant uses a keyboard to respond.

Overall, the research of Bentall, Dickins and Fox (1993), Holth and Arntzen (1998), Arntzen (2004, 2006) and O'Hora et al. (2008) supports the position that there is a link between stimulus equivalence and language. This link between stimulus equivalence and

language has been further highlighted in studies on the physiological activity during stimulus equivalence. Various studies have shown that physiological activity during stimulus equivalence is similar to activity observed during language tasks.

Physiological Measurements of Stimulus Equivalence

The first published study to report patterns of brain activation during equivalence testing was Dickins et al. (2001). The latter used an fMRI preparation to “shed light on possible underlying or mediating processes involved in stimulus equivalence” (p. 2). Participants were trained in 6 three-member classes of iconic (nameable) stimuli in a multi-stage error-free training procedure. The images used in each A-B-C class were easily nameable but semantically unrelated (e.g., A = plant, B = plane, C = dog) so that semantic relations would not facilitate training. A-B relations were trained in six blocks of training trials. In the first block the A stimulus was presented at the top of the screen and simultaneously a row of 6 boxes was presented at the bottom and a single correct B comparison stimulus was randomly inserted in one of those boxes (i.e. if the sample was A1 then the comparison was B1). No incorrect comparisons were presented at that time. The six sample-comparison pairs were presented in random order where the same stimulus was never presented twice in a row. More comparisons were gradually added in each block until all stimuli from the B class were presented in the sixth block. A mastery criterion of 19 correct out of 20 trials was applied in all blocks. The same methodology was then employed in establishing B-C relations.

Three days after finishing training, participants were exposed to an equivalence test and a test of verbal fluency while fMRI was used to monitor brain activity. Blood-oxygen-level dependence (BOLD) during the equivalence and verbal fluency tests were compared. This activation showed important similarities and differences. During the test of verbal

fluency, participants showed left-lateralized activity, especially in the dorsolateral prefrontal cortex (DLPFC) adjacent to the middle and inferior frontal gyri. These correspond to Broadmann areas 9, 44, 45, 46 and 10 as well as Broca's, areas of the brain which have been correlated with language behaviour. This part of the DLPFC was also activated during the equivalence test. The authors concluded that the similarity in activity between the equivalence test and the test of verbal fluency supported the view that there is "a linguistic basis for stimulus equivalence" (p. 5). Activity was also detected in the left posterior parietal cortex as well as lesser activity in the anterior cingulate cortex, insular and bilateral primary visual cortex, the posterior superior temporal sulcus, medial frontal cortex, left caudate nucleus and thalamus/pulvinar. During the equivalence test no task related activity was found at Broca's area and activation found in the DLPFC and posterior parietal cortex was more bilateral than during the task of verbal fluency. Additionally, the equivalence task activated the BA10 Broadmann area but did not activate the superior temporal sulcus which the verbal fluency task had done.

In a more recent study, Schlund et al. (2007) exposed participants to a two step matching to sample (MTS) equivalence procedure using various types of stimuli such as Greek letters and mathematical symbols. In the first step, participants were trained in A-B and B-C relations and in the second step they were measured for fMRI activity while exposed to equivalence testing. The MTS task in both steps was identical, with one sample and two comparison stimuli being presented in each trial and the incorrect comparison being the cross-class equivalent of the correct comparison (e.g. when B1 is correct then B2 is incorrect). Schlund et al.'s results indicated similar activation patterns as Dickins et al. for frontal and parietal regions for trained (A-B and B-C) and derived relations (pooled symmetry, transitivity and equivalence responding). The main discrepancies between Schlund et al. and Dickins et al. were that Schlund and associates failed to replicate the left lateralized

effect seen by Dickins et al. Schlund et al. observed a predominantly right cerebral activation for trained, derived, transitive and equivalence relations. These differences might have been due to differences in methodologies (gradual training vs. two step method) and stimuli used (iconic stimuli vs. Greek and mathematical symbols).

Electrophysiological Measures. Given fMRI's excellent spatial resolution, it is eminently suitable for the identification of brain areas involved in a particular task. However, this spatial resolution comes at the expense of temporal resolution. This lack of temporal resolution makes it hard to identify moment to moment changes in the brain which could contribute to complex cognition. To increase temporal accuracy, researchers employ the electroencephalograph (EEG) which measures neural electrophysiological activity with a temporal resolution of less than one thousandth of a second. Additionally, EEG can differentiate between different types of electrical brain activity, called frequencies. The frequencies of the brain are measured in Hertz (Hz), which are oscillations of a wave per second. Thus, if a wave has a frequency of 2 Hz, it will start and end in 0.5 seconds, repeating twice per second. A multitude of waves and wavelike phenomena have been discovered with the EEG, but not all of them are relevant to understanding complex behaviour and cognition. The frequencies of primary interest are delta, theta, alpha, beta and gamma. These frequencies have been linked with various activities such as remembering, speech, categorization and sleep (Fisch, 1999; Niedermeyer, 2005). The specific attributes of each of these are described below. The EEG primarily records electrical activity from the cerebral cortex (Rowan & Tolunsky, 2003); however, this activity is highly influenced by muscle activity, sub cortical electrical activity and even outside interference (Churchland & Sejnovski, 1992). Additionally, the electrical potentials generated by neurons are blocked, diffused and corrupted by the layers of brain, fluid, bone and scalp that they must pass

through before being recorded at the scalp. In light of these limitations of the EEG it is necessary to have a large number of trials in order to facilitate identifying a reliable signal.

Event related potentials. Behaviour analysts who have studied the electrophysiology of learning have used event-related potentials (ERP). ERPs are created using averaged EEG activity around a particular stimulus, and are time-locked to that stimulus (Churchland & Sejnovski, 1992). Thus, the ERP identifies averaged brain activity within a few hundred milliseconds of stimulus presentation. Barnes-Holmes et al. (2004, 2005), expanding the work of Hayes and Bissett (1998), showed that an ERP component called the N400, which has been linked with semantic processing, is sensitive to equivalence relations. The N400 is an EEG component that consists of a negative ERP deflection that occurs approximately 400ms following stimulus presentation and is most pronounced when participants are exposed to semantically unrelated stimuli (e.g., Cup-Mother). Barnes-Holmes et al. found that semantically unrelated words elicited the largest N400 response; semantically unrelated but equivalent trained words elicited a smaller response and finally semantically related words which had not been connected via equivalence training elicited next to no N400 deflection. This is further evidence that equivalence and language are related and evoke similar physiological processes. It is also worth noting that the ERPs between 350 and 550 ms after the presentation of the stimuli were greater for the left hemisphere relative to the right for the equivalent word pairs versus the non-equivalent word pairs.

Frequency measures. Despite the popularity of the ERP method, there are other approaches that have been used to measure the electrophysiological correlates of complex behaviour. Different electrophysiological (or waves) combine to make up the ERP signal. Some of these frequencies have been correlated with tasks involving language and cognition.

Traditionally, three types of frequencies, delta, theta and alpha, have been linked to cognitive and memory tasks (Klimesch, 1999). Recently, gamma, and to some extent beta,

waves have also been linked to cognition and complex behaviour (Bertrand & Tallon-Baudry, 2000; Bauer, Paz & Paré, 2007; Caplan & Glaholt, 2007). All of these frequencies can be detected with a spectral analysis of the EEG such as the Fast Fourier Transform (FFT). Although there is no clear consensus as regards the exact boundaries of the frequencies they usually fall close to the following: delta (.05 – 4 Hz), theta (4 – 8 Hz), alpha (8 – 12 Hz), beta (12 – 30 Hz) and gamma (30 – 100 Hz). Although they have many properties and functions that overlap, these frequencies can be analyzed independently of each other (see for example Brickman, 2005) and are differentially active during different tasks. For example, in 1929, Hans Berger identified the alpha frequency and its links with attention (Rowan & Tolunsky, 2003). In recent years, the alpha wave has also been linked to cognitive functions such as memory (see for example Klimesch, 1996, 1999). Although delta, theta and alpha waves can be found in both human and nonhuman mammals, alpha waves are the most prominent in the human cortex while theta and delta are more prominent in other mammals (Niedermeyer, 2005; Rowan & Tolunsky, 2003). Specifically, alpha frequencies can be detected in more locations on the scalp of human than non-human mammals and there is greater power in the alpha frequency band in humans. There are individual differences in resting alpha power and several studies (Klimesch, Vogt & Doppelmayr, 2000; Sederberg et al, 2003) have suggested that higher resting alpha power can be used to predict performance on cognitive tasks. On the whole, relatively large alpha waves and small theta and delta waves characterize individuals that do well on cognitive tasks.

As healthy adults proceed from a resting condition (i.e., eyes closed) to a testing condition, alpha power decreases while delta and theta power increases (Keane, James & Hogan, 2007; Keane & James, 2008; Klimesch, 1999). Controlling for individual differences, power in the alpha frequency is lower during tasks that require mental effort than during baseline while power in the theta and delta bands is greater during task than during baseline.

During various working memory tasks, such as mental calculation (Harmony et al., 1999, 2001), letter series recall (Onton, Delorme & Makeig, 2005) and Sternberg memory task (Jensen & Teschle, 2002), theta power increases from baseline and similar changes can be seen in delta, while the opposite is observed in alpha (Basar, Basar-Eroglu, Karakas & Schürman, 1999 and 2001; Keane, James & Hogan, 2007; Keane & James, 2008). Although the different frequencies' activity is modulated by task activity, delta, theta and gamma wave amplitude increases as a function of individual effort, while alpha and beta are more affected by task difficulty. This means that in a participant that lacks motivation solving a difficult task, changes would be recorded in the alpha and beta frequency ranges, but little changes would be observed in the delta, theta and gamma frequencies. In a participant making a concentrated effort on the other hand, changes could be seen in all frequency ranges, depending on the type of task being engaged in.

Delta (0.5-4 Hz). Delta has for a long time been associated with deep sleep (Fitch, 1999) as the quantity of delta waves increases during that time. However, delta also seems to change according to cognitive demands. Delta power, or amplitude, is lower during baseline than during demanding cognitive tasks (Sauseng & Klimesch, 2008; Schutter et al., 2005; Thatcher, North & Biver, 2005). This increase in amplitude is predominantly in parietal areas during visual oddball paradigms, but central and frontal areas as response to auditory stimuli (Başar et al., 2001). Additionally, delta has been thought to play a role in 'large scale cortical integration' (Sauseng & Klimesch, 2008, p. 1002), by combining information from various sources (see also Başar, Başar-Eroğlu, Karakaş and Schüman, 1999 and Basar et al. 2001). Baseline delta amplitude can also be used as an indicator of anxiety and cognitive capacity. Schutter et al. (2006) reported that participants with low baseline delta power were more likely to report increased anxiety levels than those with high baseline delta power. According

to Thatcher, North and Biver (2005), delta power has been positively correlated with I.Q. scores in developmentally disabled children, but not in normally developed children or adults.

Theta (4-8 Hz). More so than any other frequency, theta activity has been correlated with language and memory function. There is also evidence that theta responses are highly task sensitive, both in terms of topography (where the activity occurs) and frequency amplitude (response strength). According to Sauseng et al. (2002; 2004) the location of theta activity can change based on the response demands in a task. Sauseng et al. found that during training in a memory task, theta was initially activated in frontal regions and moved to posterior regions within 500 milliseconds. When participants were required to recall information, theta activity was first registered at posterior locations after 500 ms and then moved forward. The most thoroughly established theta phenomenon is the midline frontal theta which is selectively active during working memory (Onton, Delorme & Makeig, 2005). When participants are exposed to a task that tests their working memory abilities using words or pictures, the amount of activity in this area is affected. Not only does the amplitude of theta increase linearly with increased task difficulty (Grunwald et al., 1999; Jensen & Tasche, 2002; Onton Delorme & Makeig, 2005), but the amount of increase from baseline to task is also positively correlated with task performance (Klimesch & Doppelmayr, 2000; Klimesch et al, 2001; Brickman et al., 2005). When participants have to engage in mental arithmetic, theta activity shifts towards the dorsolateral prefrontal cortex (Harmony et al, 1999), which has been taken to indicate separate functions of theta activity in different cortical locations. Theta activity changes reliably when verbal stimuli are presented. Specifically, it increases in amplitude following the presentation of verbal stimuli (Grabner et al., 2007) specifically in the temporal-occipital regions (Harmony et al., 2001). Hald, Bastiaansen & Hagoort (2006), reported increases in theta amplitude after the presentation of sentences that included a semantic violation. This increase was most prominent in temporal and mid frontal areas.

After the presentation of sentences with no semantic violation, this increase was visible bilaterally at temporal locations.

Alpha (8-12 Hz). Even if the alpha frequency was the first EEG frequency to be discovered, only recently was it linked to cognitive functions. It is well established that alpha amplitude is higher when participants are not engaged in any mentally tasking activity (Fisch, 1999; Rowan & Tolunsky, 2003), in fact, simply closing one's eyes will increase alpha amplitude. Recently, researchers have been discovering that alpha activity is correlated with very specific cognitive activity and that baseline alpha activity can be used to predict performance on various cognitive tasks (see for example Klimesch, 1996, 1997, 1999; Bell & Cox, 2007). Bell & Cox found that adults who scored high on the Beck Depression Inventory (BDI) showed greater right frontal alpha power than those who score low on the BDI. Conversely, adults with low scores on the BDI show greater activation in the left frontal areas than those that score high on the BDI. Changes in alpha power have also been linked to various verbal and language related tasks, such as translation (Grabner et al., 2007), and word and figure categorization (Harmony et al., 2001). Grabner et al. found that approximately 200-400 ms after word presentation, alpha amplitude increased in the frontal areas if the words presented were low frequency words. However, if the word presented was common, no activity changes were recorded in the frontal areas. Translation then increased activity in the left hemisphere but not the right hemisphere. Harmony et al. also found changes in alpha power related to categorization of both words and images and that stimulus presentation resulted in increased alpha activity. No specific changes due to either words or images were found in the alpha frequencies, indicating that alpha activity is related to general categorization rather than specific types of categorization. Operant conditioning is believed to have very limited effects on activity in the alpha frequency. Keil et al. (2001) exposed participants to a three staged experimental protocol designed to explore the

electrophysiological activity during operant learning. First, participants were exposed to a 'shaping condition' where continuous reinforcement was delivered for button pressing. Next, the participants were placed on a variable interval schedule which was used as a control condition to the previous stage. Finally, as a further control condition, participants were allowed to press the button at their own leisure, without reinforcement. The authors noted that during the operant shaping procedure, alpha power was reduced in posterior and anterior sites which would be expected when engaging in any task. Alpha activity was also reduced in the left hemisphere in the first 250 ms after participants engaged in the operant procedure. However, no further changes in alpha activity were recorded during the task. Nevertheless, alpha might be correlated with response behaviour in more complex cognitive tasks such as translation and categorization.

Beta (12-30 Hz). Overall, beta activity largely mirrors alpha activity (Rowan and Tolunsky, 2003). However, like the alpha frequency, recent research has found that beta might change only as a response to specific environmental variables. Some of these changes are specific only to beta, but not the alpha, as was previously thought. One difficulty in analyzing beta and gamma frequencies and their responses to cognitive tasks is that both frequencies are very active in the temporal regions. Those regions are responsible for muscle movement, such as hand and finger movement, so any activity in those areas has to be interpreted with caution. The activity might not be a response to any environmental activity, but simply muscle movement as participants respond to stimuli (see Hwang et al., 2005). Hwang et al. found that beta activity was increased when participants had to sub-vocally rehearse a series of words and that this activity increase from baseline was concentrated in the mid frontal and mid parietal regions. Klimesch and Doppelmayr (2000) reported that participants that performed well on a mental arithmetic task had more beta power than participants that performed poorly. This difference was visible both during actual task

performance and during two baseline conditions. Similar to alpha, beta activity also shows hemispheric differences based on performance. According to Papousek & Schuster (2004), participants that performed well on a task of verbal fluency had more beta activity in the left hemisphere than the right. Also, the difference in activity was linearly correlated to performance on the task. Beta also shows specific responses to operant conditioning, similar to those seen in alpha. Compared to baseline, beta power decreased during operant conditioning, specifically in posterior regions.

Gamma (30-80 Hz). Gamma frequencies have long been associated with conscious awareness, and are thought to bind elements of consciousness together (Revonsuo & Newman, 2001) and therefore play a key part in solving the so called ‘binding problem’. The binding problem, according to Revonsuo & Newman (p. 123) is “the problem of how the unity of conscious perception is brought about by the distributed activities of the central nervous system”. This interpretation of gamma has been very controversial, with some authors claiming that 40 Hz gamma activity should be interpreted as eye movement artefacts (Yuval-Greenberg, Tomer, Keren, Nelken & Deouell, 2008) with no clear functional properties. However, there is strong evidence to suggest that gamma activity does correlate with performance on tasks of language and memory (Fründ & Herrmann, 2007) and is affected by operant conditioning (Miltner, Braun, Arnold, Witte & Taub, 1999; Keil et al. 2001). Fründ & Herrmann reported that gamma activity increased when participants needed to compare stimuli with stimuli that had been presented earlier in the experiment. Herrmann et al. (2004) later reported that when participants had to actively rehearse (or maintain stimuli in working memory), gamma activity was increased in the occipital cortex (see also Bertrand & Tallon-Baudry, 2000). In 2006, Hald, Bastiaansen & Hagoort reported that gamma frequencies in frontal areas showed an increase in amplitude when participants had to process correct sentences. However, no changes in amplitude were observed following the

presentation or processing of sentences that included semantic violations. As in the alpha frequency, differences between groups can be found in the gamma frequency. Jausovec & Jausovec (2005) reported that participants that performed well on a task of verbal intelligence showed greater alpha and gamma activity in the parietal regions. However, participants that performed poorly had greater activity in the frontal areas of the brain. Additionally, the good performers had faster activity, showing changes in EEG activity sooner than poor performers.

By analyzing the raw EEG signal using FFT, it is possible to decompose the average brain activity following stimulus presentation. FFT can be used to identify the spectral power of a particular frequency that is associated with observed activity. For example, it can be observed that during a memory task, theta frequency is proportionately lower compared to baseline, than delta; hence, theta is correlated with the task being solved, while delta is not. Spectral power analyses (such as FFT) of electrophysiological activity provide ongoing data on neuronal activity that may provide information concerning functional differences with respect to the formation of stimulus equivalence classes (see for example Deutsch, Oross, DiFiore & McIlvane, 2000 and Roche, Linehan, Ward, Dymond & Rehfeldt, 2004). To date, one study has been published that employed spectral analysis of electrophysiological activity during derived relational responding (Roche et al., 2004). The researchers concluded that alpha activity above the frontal midline and left temporal lobe correlated positively with proficiency on the task. This corresponds to the results previously reported by Dickins et al. (2001) and Schlund et al. (2005), pointing again to these regions as the most relevant to stimulus equivalence relevant activity.

Summary and Aims of the Thesis

The aim of the study was to extend previous research on the biological aspects of stimulus equivalence and derived relations by using a variation of a well established protocol

used by Dickins et al. (2001). By doing this, it would be possible to predict performance on equivalence tasks using physiological variables and lay the foundation for an eventual physiological intervention using such techniques as transcranial magnetic stimulation (TMS) to improve performance. Additionally, the aim was to develop an experimental protocol which was well suited to EEG research and at the same time fulfilled the requirements of stimulus equivalence research. Although a linear protocol is not the preferred method of training in derived relational responding research it has been used by authors investigating the biological correlates of derived relational responding (Dickins et al., 2001; Schlund et al., 2007) and was therefore employed in all the experiments in this study.

In contrast to Dickins' et al. search for anatomical locations active during equivalence, this study looked at oscillations most commonly associated with language, cognition and memory. Delta was predicted to show an overall increase in task conditions compared to baseline and temporal and posterior regions were expected to be more active during task conditions than during baseline. Theta was predicted to show an overall decrease from baseline to task and to be most prominent in the frontal and temporal regions during task conditions. Lastly, alpha activity was expected to decrease from baseline to both training and testing and that theta and delta activity would show an overall increase. During baseline alpha activity was expected to increase more in the occipital areas than in other areas, though this difference would be expected to be minimal during task conditions (Niedermeyer, 2005). Later, beta and gamma frequencies were added in later experiments as event related gamma in particular has been linked with performance on categorization tasks (Herrmann et al. 2004).

Stimulus types were predicted to influence the outcome of the equivalence tests. It was expected that participants exposed to iconic stimuli would learn conditional discriminations faster than participants exposed to abstract stimuli. However, the numbers of

participants that displayed equivalence in each group were expected to be similar. The different stimuli should call for different private verbal behaviour by the participants as recognizable stimuli can fall into an already established equivalence class whereas abstract stimuli do not. Therefore, the EEG pattern during learning should be different. Alpha power in participants exposed to the iconic stimuli was expected to be higher than in participants exposed to abstract stimuli, as alpha activity has been found to coincide with language behaviour. Conversely, the theta and delta power of participants exposed to abstract stimuli was expected to be higher than in those exposed to iconic stimuli, as those participants would have to rely on visual information and short term memory which has been associated with delta and theta power. These differences were predicted to be located mostly in the left and frontal regions where activity has been associated with language behaviour.

Chapter 2: Study 1

Experiment 1.1

In the previous chapter, a number of features of the literature on stimulus equivalence were detailed; most notably its relation to language (see for example Devany, Hayes & Nelson, 1986) and other complex learning (Hayes & Bissett, 1998). As the research on equivalence has advanced, the most logical way for researchers has been to look to physiological processes that accompany stimulus equivalence behaviour. An overview of the literature indicates that much of the physiological activity that accompanies equivalence is of the same type that accompanies language activity (Dickins et al., 2001; Barnes-Holmes et al.; 2004, 2005; Schlund et al., 2007). So far the electrophysiological activity that accompanies equivalence has mostly been researched using the ERP method (Barnes-Holmes et al., 2004, 2005, although for an alternative view see Roche et al., 2004). Despite the temporal accuracy of the ERP method, it has some disadvantages. The signal detected using ERP is the product of many sources of activity in different areas of the brain. Furthermore, different electrophysiological frequencies (or waves) combine to make up the ERP signal. Some of these frequencies have been correlated with tasks involving language and cognition (see Chapter 1 for review). By analyzing the raw EEG signal using Fast Fourier Transform (FFT), it is possible to decompose the average brain activity following stimulus presentation. FFT can be used to identify the spectral power of a particular frequency that is associated with observed activity.

Although many of the physiological characteristics of equivalence responding have been explored, very little is known about any possible physiological prerequisites of successful equivalence class formation. If there are specific neurological functions or activities that facilitate equivalence, it is imperative that the physiological activity that precedes equivalence responding is charted.

The main goal of Experiment 1.1 was to attempt to record EEG activity during both training and testing of equivalence in order to compare brain activity in participants that displayed equivalence and those that did not. Although no such analysis had previously been undertaken Dickins et al. (2001) did measure brain activity using fMRI. The protocol used by Dickins et al., where participants were trained in 6 three-member classes of iconic (nameable) stimuli in a multi-stage error-free training procedure, served as a template for the current research in order to facilitate comparison between the studies. The stimuli used were also the same iconic, easily nameable as Dickins et al. used in their study, grouped together in 6 3-member classes (A1-B1-C1, A2-B2-C2, A3-B3-C3, A4-B4-C4, A5-B5-C5 and A6-B6-C6). Not only would this ease the comparison between the two studies, but iconic stimuli can induce private rule governed behaviour and ease the formation of equivalence classes due to the participants learning history with those stimuli (see for example Dickins, Bentall and Smith, 1993). Employing the same protocol in later experiments, but using different stimuli, it would also be possible to isolate context free learning in the brain by comparing the results from the two types of stimuli.

Method.

Participants. Thirteen healthy adult human (4 male) participants took part in the study. All were between 17 and 25 years of age, right handed and with normal or corrected to normal eyesight; none reported taking psychotropic medication, or having sustained traumatic brain injury. All participants were first year students at the National University of Ireland Galway and participated to gain course credit. The study was approved by the NUI Galway Research Ethics Committee.

Apparatus. Training and testing involved a PC computer with Microsoft Visual Basic 6 (VB) software for stimulus presentation and recording of behavioural data. Iconic stimuli (easily recognizable and nameable) were adopted from Dickins et al. (2001) and were

presented on a Compaq S716 16' monitor using a Windows 98 operating system. A Quick-Amp 40 EEG amplifier (Brain Products, GmbH, München, Germany) was used with BrainVision Recorder (v. 1.03.0001) and BrainVision Analyser (v. 1.05) software and signal was recorded from the following 32 sites (which are in accordance with the international 10-20 electrode placement system): Fp1, Fp2, F3, F4, C3, C4, P3, P4, O1, O2, F7, F8, T7, T8, P7, P8, Fz, Cz, Pz, FC1, FC2, CP1, CP2, FC5, FC6, CP5, CP6, TP9, TP10, PO9, Iz and PO10. Silver/silver-chloride (Ag/AgCl) recessed ring electrodes were used. All electrode cables were individually shielded (ActiShield™) and all channels were amplified against the average of all connected inputs.

Stimuli. The stimuli were grouped together in 6 3-member classes (A1-B1-C1, A2-B2-C2, A3-B3-C3, A4-B4-C4, A5-B5-C5 and A6-B6-C6). Alphanumeric labels refer to images used in the experiment (see Figure 1 for a depiction of all stimuli used along with their respective labels) but were not known to any of the participants.














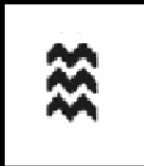




	A	B	C
1			
2			
3			
4			
5			
6			

Figure 1. Stimuli used in Experiment 1.1, sorted by equivalence classes and alphanumeric denotations.

General procedure. Volunteers signed up for research participation on the School of Psychology's internal website. On the website the experiment was described as a memory and categorization experiment for which participants were required to be right handed, not suffering from traumatic brain injuries or debilitating brain diseases and free of psychotropic medication. Upon arrival at the laboratory, participants signed the informed consent form (see Appendix 1) and filled out a questionnaire regarding traumatic brain injury and psychotropic medication. Handedness was then assessed verbally by the experimenter. After participants

had completed the demographic questionnaire and their handedness had been evaluated they were prepared for EEG (see below). They were seated comfortably in front of the computer in the experimental cubicle and were asked to relax for 5 minutes with eyes closed and for 5 minutes with eyes open. These 10 minutes constituted the EEG baseline. The following instructions were delivered verbally to all the participants by the experimenter:

Thank you for participating in the experiment. The experiment is a memory and categorization experiment in several stages during which we will monitor your brain activity. We will ask you to close your eyes for 5 minutes and relax and then relax with your eyes open for another 5 minutes. After that the task will begin. First, you will see an image on the screen and a row of empty boxes. Shortly after that, an image will appear in one of the boxes and you can choose that image using the mouse.

Gradually, all the boxes will be filled with images and you will have to remember which image in the bottom boxes corresponds, or goes with, the image you see on top of the screen. The computer will give you feedback for most of the time, but that feedback will stop at some stage. If you feel discomfort at any stage, you are free to terminate the session.

Following this the participants' baseline EEG activity was recorded and then the task began. The task was split into seven experimental stages each of which are described in detail in the following pages and depicted in Figure 2. Stage 1 consisted of six blocks of AB training; Stage 2 consisted of six blocks of BC training; Stage 3 involved one block of mixed AB and BC training; Stage 4 involved one block of mixed AB and BC testing; Stage 5 consisted of one block of symmetry testing; Stage 6 consisted of one block of transitivity testing and Stage 7 involved one block of equivalence testing. During all stages, stimuli remained on the screen until a response was emitted.

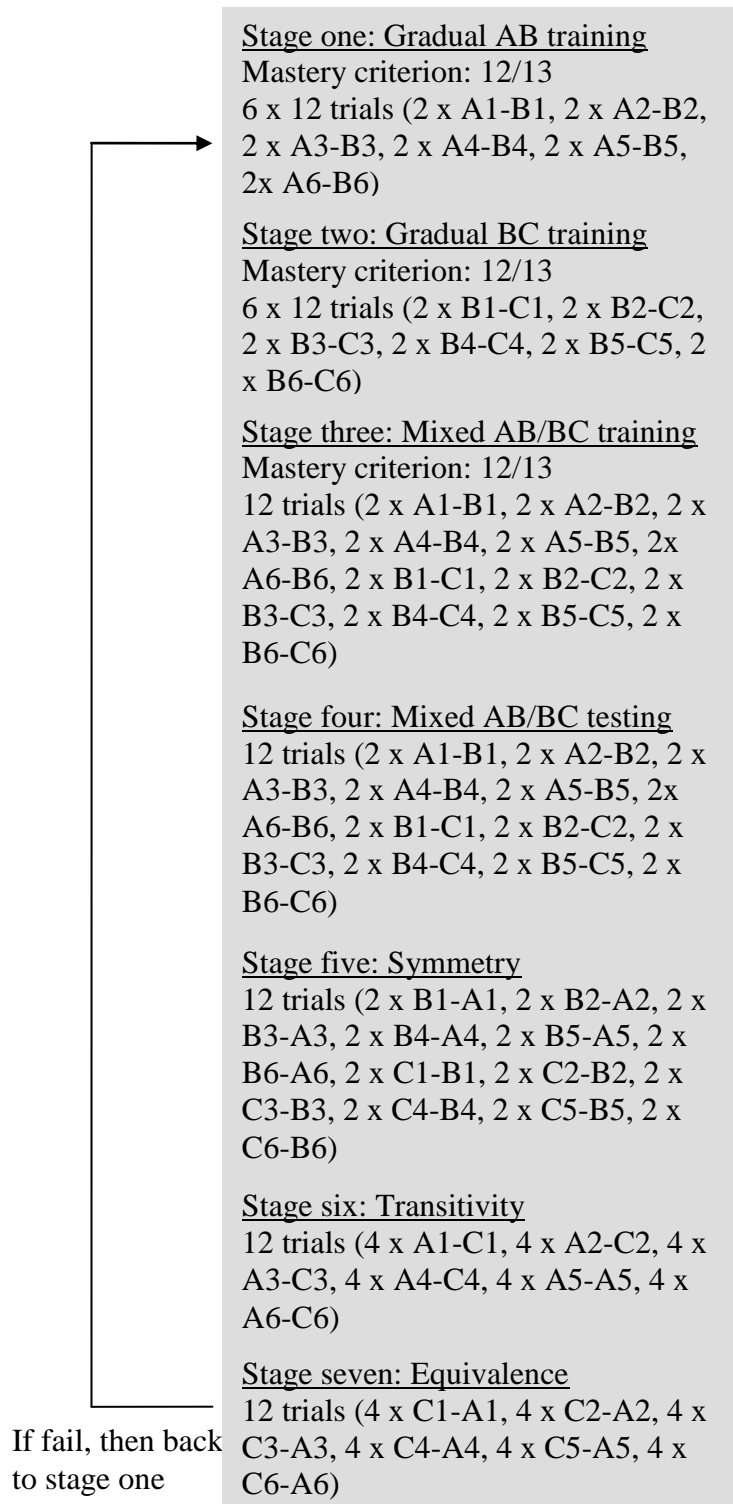


Figure 2. Schematic outline of Experiment 1.1.

EEG data preparation and analysis. Each electrode site was prepared by abrading the skin and bridging the gap between the electrode and the scalp with a chloride-free

abrasive electrolyte gel. Impedances were assessed using BrainVision Recorder (v. 1.03) software (Brain Products, GmbH, München, Germany) and were kept below 8 k Ω . Silver/silver-chloride (Ag/AgCl) recessed ring electrodes were used. All electrode cables were individually shielded (ActiShield™) and all channels were amplified against the average of all connected inputs. A QuickAmp 40 EEG amplifier (Brain Products, GmbH, München, Germany) was used in conjunction with BrainVision Recorder and BrainVision Analyser (v. 1.05.0003) software (Brain Products, GmbH, München, Germany). Sampling rate was 1000 Hz during recording, and changed to 1024 during analysis to adhere to the requirements of FFT. Frequencies between 0.5-12.5 Hz were used for analysis. Vertical (VEOG) and horizontal (HEOG) ocular activity was measured via EOG channels mounted at the outer canthi of the right and left eyes, and approximately 2cm above and below the left eye, respectively. Following offline ocular correction, artefact free, 2000 ms epochs of EEG data following the presentation of comparison stimuli were selected for analysis. These epochs were chosen irrespective of correct or incorrect responses.

The 32 electrodes were grouped into 9 regions divided along the coronal (front to back) and sagittal (left to right) planes: Left Frontal (LF), Mid Frontal (MF), Right Frontal (RF), Left Central (LC), Mid Central (MC), Right Central (RC), Left Posterior (LP), Mid Posterior (MP) and Right Posterior (RP) (see Keane, James & Hogan, 2007; Keane & James, 2008). The electrode placement can be seen in Figure 3 below.

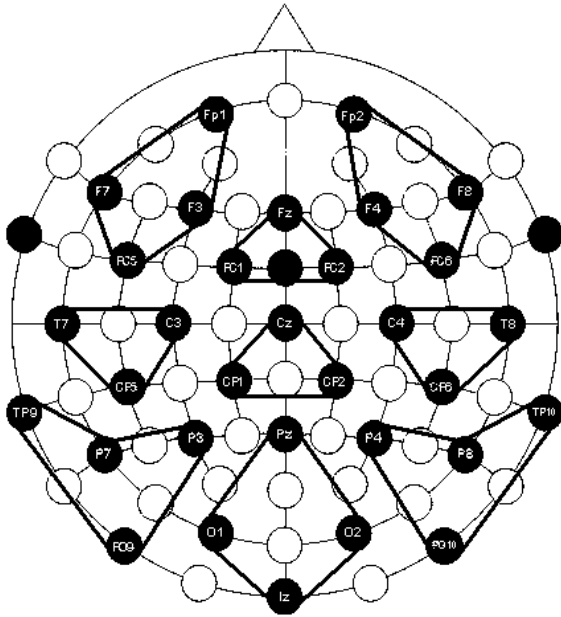


Figure 3. Electrode grouping used for EEG analysis

Conditional discrimination training. Conditional discriminations, necessary for the formation of six three member equivalence classes in the task, were trained using a gradual error-free linear protocol. All trials were matching to sample (MTS) and were designed in the same way: A blank screen, which acted as the inter trial interval, was presented for 500 ms. Then the sample appeared for 1000 ms at the top centre of the screen before the comparison(s) were presented at the bottom of the screen. Both the sample and comparisons remained on the screen until a response was made. All stimuli were easily nameable images (see Figure 1) adopted from Dickins et al. (2001). The images were presented within a black border and measured 4x4 cm. Following the response, the stimuli were removed and feedback, either ‘Correct’ (in green) or ‘Wrong’ (in red), was presented in 48 pt. Times New Roman font at the centre of the screen for 1000 ms followed by the inter-trial interval. The conditional discrimination training included three stages. Stages 1 and 2 employed gradual training as follows. In Stage 1 the following conditional discriminations were trained: A1 → B1, A2 → B2, A3 → B3, A4 → B4, A5 → B5 and A6 → B6. In the first trial in the first block in Stage 1, one B stimulus was presented in the presence of the corresponding A stimulus (B1

in the presence of A1, see Figure 4, upper panel). In this block, participants chose the only available stimulus and feedback was provided. In each subsequent block of Stage 1 one further comparison was presented. Finally, in block 6, all six possible comparisons were presented (See Figure 4, lower panel). A mastery criterion of 12 cumulative correct, which allowed for one incorrect response (12 out of 13 cumulative correct was considered to have satisfied the mastery criterion), was employed in all blocks in Stage 1. Participants did not advance to the subsequent block (increased number of incorrect stimuli added as comparisons) without reaching this criterion. Stage 2 was identical to Stage 1, except that it involved B-C rather than A-B training and thus the following conditional discriminations were trained: B1 → C1, B2 → C2, B3 → C3, B4 → C4, B5 → C5 and B6 → C6.

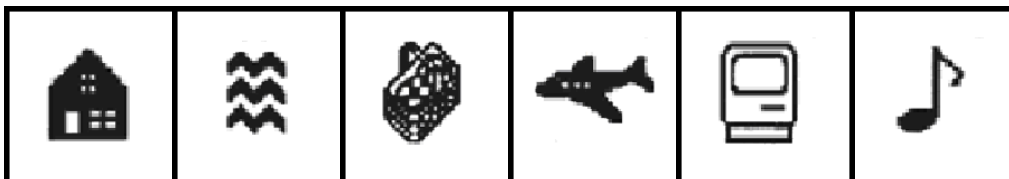


Figure 4. Screen shots from A-B training in Block 1 in Stage 1 (Upper Panel) and Block 6 in Stage 1 (Lower Panel).

Stage 3 was a single mixed training block that trained all A-B and B-C conditional discriminations in the final block format of stages 1 and 2 (i.e., in which participants were required to choose the one correct stimulus out of 6 possible comparisons). The following conditional discriminations were trained: A1 → B1, A2 → B2, A3 → B3, A4 → B4, A5 → B5, A6 → B6, B1 → C1, B2 → C2, B3 → C3, B4 → C4, B5 → C5 and B6 → C6. As in previous stages, a mastery criterion of 12 cumulative correct, which allowed for one incorrect response, was employed.

After reaching the mastery criterion in each block, a message appeared on the screen reminding participants to take a short break. A similar message appeared after participants finished all training stages. The minimum number of trials required to complete stages 1 and 2 was 72 (6 blocks of 12 trials), and the minimum number of trials required in Stage 3 was 12 trials. If participants did not reach the testing stage within 80 minutes of initiating training the experimental session was terminated.

Testing baseline and derived relations. Stage 4 was a single mixed testing block, consisting of 12 trials, which tested all A-B and B-C conditional discriminations from Stage 3. The following conditional discriminations were tested: A1 → B1, A2 → B2, A3 → B3, A4 → B4, A5 → B5, A6 → B6, B1 → C1, B2 → C2, B3 → C3, B4 → C4, B5 → C5 and B6 → C6. All trials were MTS which started with a blank screen, which acted as the inter trial interval, presented for 500 ms. The sample then appeared for 1000 ms at the top centre of the screen before the comparisons were presented at the bottom of the screen. Both the sample and comparisons remained on the screen until a response was made. Following the response, the stimuli were removed and the inter-trial interval (ITI) blank screen was presented for 500 ms. A mastery criterion was employed where the participants had to respond correctly to 11 out of 12 trials in the stage. However, participants were allowed to advance through all test stages regardless of performance. If they did not reach the criterion, they were re-exposed to the training from Stage 1 only after finishing Stage 7.

Stage 5 was a single mixed testing block, consisting of 12 trials, which tested all symmetrical relations (B1 → C1, B2 → C2, B3 → C3, B4 → C4, B5 → C5 and B6 → C6). Stage 6 was a single mixed testing block, consisting of 12 trials, which tested all transitive relations (A1 → C1, A2 → C2, A3 → C3, A4 → C4, A5 → C5 and A6 → C6). Stage 7 was a single mixed testing block, consisting of 12 trials which tested all equivalence relations (C1 → A1, C2 → A2, C3 → A3, C4 → A4, C5 → A5 and C6 → A6). Sample and comparison

locations on the computer screen, ITI and mastery criterion in Stages 5 to 7 were identical to those in Stage 4. If participants did not demonstrate equivalence in Stage 7, they were re-exposed to the procedure beginning from Stage 1. A schematic representation of the experimental procedure can be seen in Figure 2.

Results. Nineteen participants were recruited for the experiment; 12 participants displayed equivalence on the first exposure and one on the third exposure. Five participants did not display equivalence. Participants 3, 5 and 17 were exposed to the protocol three times, displaying similar performances in each exposure. Participant 7 never advanced past the first stage of training and the experiment was terminated after 80 minutes. Lastly, Participant 9 dropped out after failing equivalence on the first exposure. Results for equivalence training and testing for the remaining 18 participants can be seen in Table 1. As can be seen below Participant 1 completed 72 trials of A-B training, followed by 72 trials of B-C training and finally 12 trials of mixed AB-BC trials. Following this the participant was exposed to four stages of testing, each with 12 trials. In the AB-BC Mixed, Symmetry and Equivalence stages the Participant responded correctly in all 12 trials. In the Transitivity test, the Participant only responded incorrectly once.

Table 1.

Total number of trials during training phases and number of correct responses during testing phases

	Training				Testing			
	A-B	B-C	AB-BC	Total	AB-BC Mixed	Symmetry	Transitivity	Equivalence
1 ¹	72	72	12	156	12/12	12/12	11/12	12/12
2 ¹	74	73	12	159	12/12	12/12	11/12	12/12
3 ²	95	72	13	180	11/12	11/12	2/12	0/12
	73	72	13	158	12/12	12/12	4/12	2/12
	72	73	12	157	12/12	12/12	0/12	2/12
4 ¹	72	73	12	157	11/12	12/12	12/12	12/12
5	141	94	12	247	12/12	12/12	4/12	5/12
	72	72	12	156	12/12	12/12	1/12	3/12
	72	73	12	157	12/12	12/12	2/12	2/12
6 ²	75	72	12	159	12/12	12/12	12/12	12/12
7 ³	829	----	----	829	----	----	----	----
8 ²	84	72	13	169	12/12	12/12	12/12	12/12
9 ²	72	72	12	156	12/12	12/12	2/12	2/12
10 ¹	85	74	12	171	12/12	12/12	10/12	12/12
11 ²	72	72	12	156	12/12	12/12	2/12	1/12
	72	72	12	156	12/12	12/12	2/12	1/12
	72	73	13	158	12/12	12/12	11/12	12/12
12 ²	92	72	39	203	11/12	12/12	11/12	12/12
13 ¹	72	74	12	158	12/12	12/12	12/12	12/12
14 ¹	74	73	12	159	12/12	12/12	9/12	12/12
15 ¹	132	75	12	219	12/12	11/12	11/12	11/12
16 ¹	73	74	12	159	11/12	12/12	8/12	12/12
17	74	72	12	158	12/12	12/12	1/12	0/12
	74	72	12	158	12/12	12/12	2/12	0/12
	72	72	12	156	12/12	12/12	2/12	1/12
18 ¹	72	72	12	156	12/12	12/12	11/12	12/12

¹ Data included in the final EEG analysis

² EEG data not recorded due to program error

³ Training terminated after 80 minutes

Behavioural results. Overall, little relationship was found between performance in the Training and Testing stages. Thirteen of the 18 participants did display equivalence and

one participant never advanced through A-B training, leaving only 4 participants in the Fail group to compare to the 13 that passed. Any comparison of the two groups is therefore very difficult, due to the small sample in the Fail group. The majority of participants were quick to learn the A-B pairing. The minimum number of trials needed to advance through training was 72 trials in both A-B and B-C training, and 12 in the mixed A-B/B-C training. Nine participants showed an almost immediate acquisition, with 75 trials or less in the first exposure to the A-B training. Participants 3 and 5 needed 95 and 141 trials respectively to advance to B-C training in the first exposure to the protocol. However, in subsequent exposures, only 72 or 73 exposures were needed. Participant 7 did not advance through the A-B training stage and training was terminated after 80 minutes and 829 trials. Participants 8, 10, 12 and 15 all needed 85 trials or more to master the A-B pairing, but all displayed equivalence. Of the 17 participants that were exposed to B-C training, all but one finished that stage with 75 trials or less on the first exposure. Participant 5 needed 94 trials to advance on the first exposure, however, in the 2nd and 3rd exposure, needed only 72 and 73 respectively. In the mixed A-B/B-C training, 16 of the 17 participants needed 12 or 13 trials to advance to the testing stages. Participant 12 needed 39 trials to master the mixed training, but subsequently displayed equivalence on the first exposure.

All participants passed the mixed A-B/B-C and Symmetry (B-A and C-B) testing stages. Ten of the 13 participants that displayed Equivalence also displayed Transitivity (A-C). Participants 10, 14 and 16, correctly identified 10, 9 and 8 pairs respectively in the Transitivity stage. None of the four participants that failed to display Equivalence displayed Transitivity. Thirteen participants displayed Equivalence (C-A), and of those only one (Participant 11) needed more than one exposure to the protocol.

EEG results. EEG data from 6 participants, including 2 that did not display equivalence, was lost due to a program error. EEG data were therefore only analyzed for the

8 remaining participants that displayed equivalence. All those participants displayed equivalence on their first exposure to Stage 7. The following were chosen for analysis: Baseline, Stage 3 (AB-BC mixed training or Training) and Stage 7 (C-A equivalence or Testing) as little behavioural variability was found between participants in these stages. Frequency bands are presented in ascending order of frequency, from the slowest (delta) to the fastest (alpha). Statistical analysis consisted of first a 3x3x3 (Stage x Front-Central-Posterior regions x Left-Mid-Right regions) repeated measures ANOVA on each of the frequency bands. If a significant effect was detected in the 3x3x3 ANOVA, a one-way repeated measures ANOVA was then performed on each of the nine regions. Holm-Bonferroni corrections were applied to the p values (critical value .0056) of the one-way repeated measures ANOVAs. Additionally, all the regions were collapsed into one for a grand average measure by adding the region values together and dividing that number by nine. Holm-Bonferroni corrections were used on all pairwise comparisons (critical value .0167) within each individual region (differences between the experimental stages).

Delta (.05 – 3.5 Hz). A 3x3x3 repeated measures ANOVA found a significant Stage effect ($F_{2, 14} = 10.99, p = .001, \eta_p^2 = .611$) on delta power. This effect can be attributed to delta being significantly lower during Baseline ($36.45 \mu V^2$) than during either Training ($57.45 \mu V^2, p < .001$) or Testing ($55.20 \mu V^2, p = .019$) (see Figure 5) as was predicted. No significant differences were found between the two task stages. Significant interaction effects were also found between Stage and Sagittal (Left-Mid-Right) regions, ($F_{2, 28} = 3.1, p = .031, \eta_p^2 = .307$); between Stage and Coronal (Front-Central-Posterior) regions, ($F_{2, 28} = 3.93, p = .012, \eta_p^2 = .360$), between Sagittal and Coronal regions, ($F_{2, 28} = 4.157, p = .009, \eta_p^2 = .373$). Finally, a Stage x Sagittal x Coronal interaction effect was found, ($F_{8, 56} = 2.324, p = .031, \eta_p^2 = .249$).

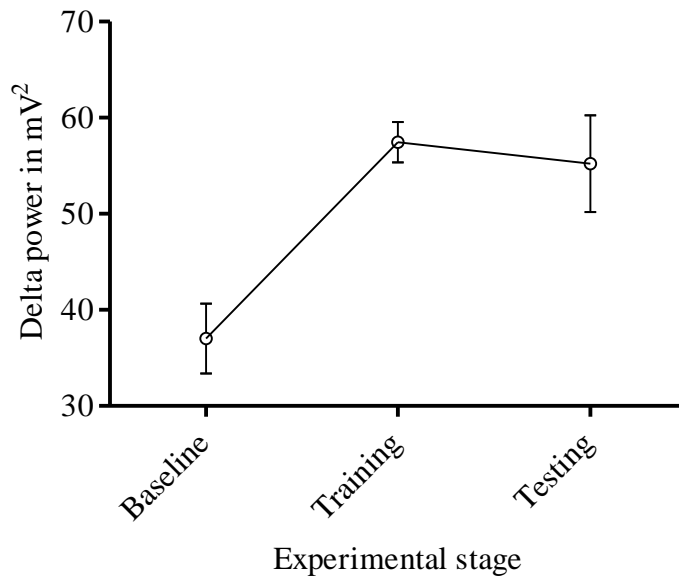


Figure 5. Grand average delta power in μV^2 in all 9 regions during Baseline, Training and Testing in Experiment 1.1.

To further explore the Stage effects on different regions a one way repeated measure ANOVA was performed at each of the nine regions to assess any changes in EEG power during the three experimental stages. Average delta power values and standard errors in all 9 regions can be seen in Figure 6 below. As can be seen, delta power was lower during Baseline, at all locations, than during either Training or Testing. Moreover, the midline and right regions showed more changes throughout the experiment than the left regions.

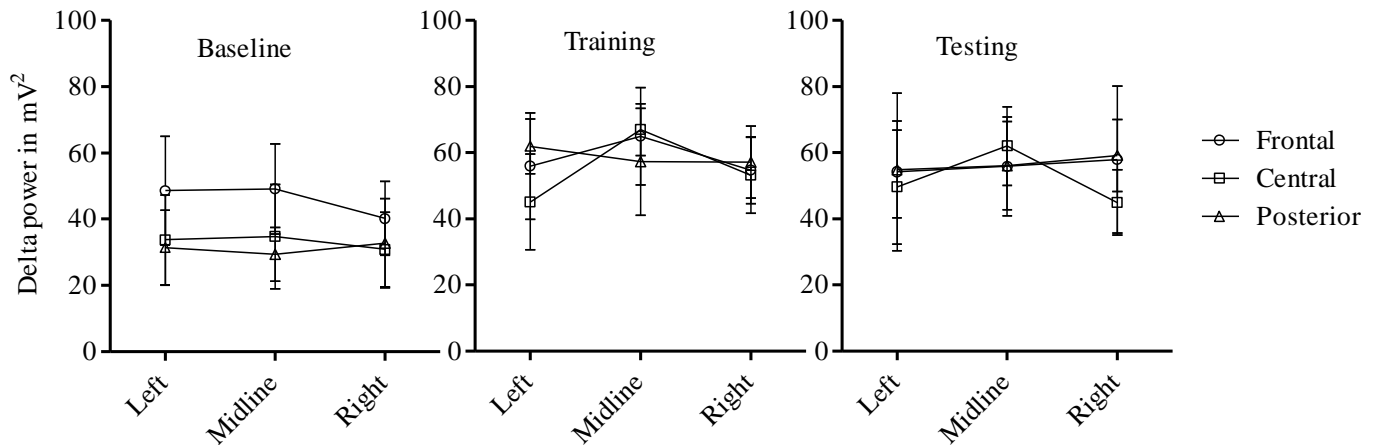


Figure 6. Average delta power values and standard error in all 9 regions used for analysis during Baseline, Training and Testing in Experiment 1.1.

The F , p and η_p^2 values and degrees of freedom are summarized in Table 2.

Table 2.

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 1.1 at each of the brain regions for the delta frequency

Brain region	Delta (0.5-3.5 Hz)			
	F	p	η_p^2	df
LF	.524	.602	.062	2, 16
MF	6.184	.010*	.436	2, 16
RF	1.028	.380	.114	2, 16
LC	4.787	.023	.374	2, 16
MC	16.567	<.001*	.674	2, 16
RC	11.229	.001*	.584	2, 16
LP	15.895	<.001*	.665	2, 16
MP	15.082	<.001*	.653	2, 16
RP	15.436	<.001*	.659	2, 16

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

*Significant effect following Holm-Bonferroni corrections

Following Holm-Bonferroni correction a significant effect of Stage on delta power was found at all but three (Left- Frontal, Right-Frontal and Left-Central) brain regions. The greatest increase in delta power was at Posterior regions and the smallest increase was at Frontal regions. Additionally, the midline regions all showed a significant effect and the Mid-Central region showing the strongest effect of all nine regions. However, none of these effects can be attributed to differences between Training and Testing. A significant difference was found between Baseline and Training in the Mid-Frontal ($p = .011$), Right-Central ($p < .001$) and Left-Posterior regions ($p = .001$). However, only the Left-Posterior differences had a medium effect size. No difference was found in these regions between Baseline and Testing. Baseline was significantly higher than both Training and Testing in the Mid-Central ($p = .002$ and $.011$), Mid-Posterior ($p = .008$ and $.005$) and Right-Posterior ($p = .010$ and $.002$) regions and all these effects sizes were medium.

Theta (3.5 – 7.5 Hz). A repeated measures 3x3x3 ANOVA found no significant effects in theta power. Small changes were observed in overall average theta power between the three Stages (see Figure 7 below), however these were not significant ($F_{2, 14} = 1.134$, $p = .350$, $\eta_p^2 = .139$). No further analysis was conducted on theta power.

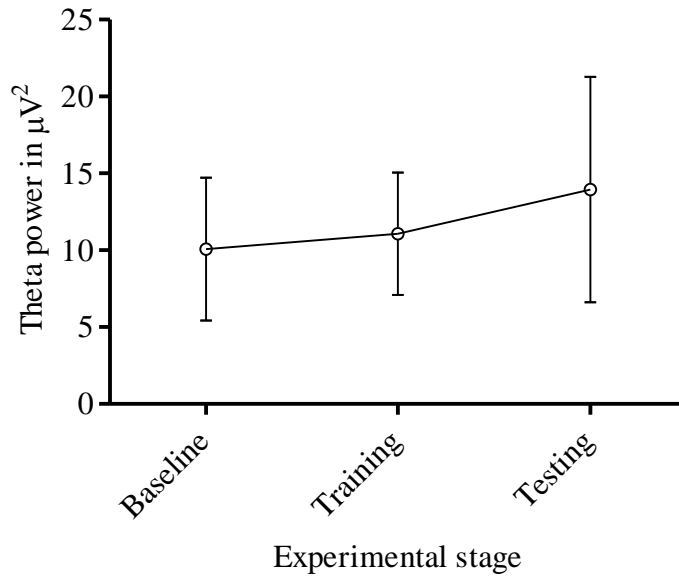


Figure 7. Grand average theta power in μV^2 in all 9 regions during Baseline, Training and Testing in Experiment 1.1.

Alpha (7.5 – 12 Hz.) A 3x3x3 repeated measures ANOVA found a significant Stage effect, ($F_{2, 14} = 22.565, p < .001, \eta_p^2 = .763$), on alpha power. Alpha power was lower during both Training ($p = .001$) and Testing ($p = .003$) than during Baseline (see Figure 8 below). This illustrates the validity of the experimental protocol, as the suppression of alpha during a cognitive task is one of the most robust findings in the EEG literature (see for example Finch, 1999).

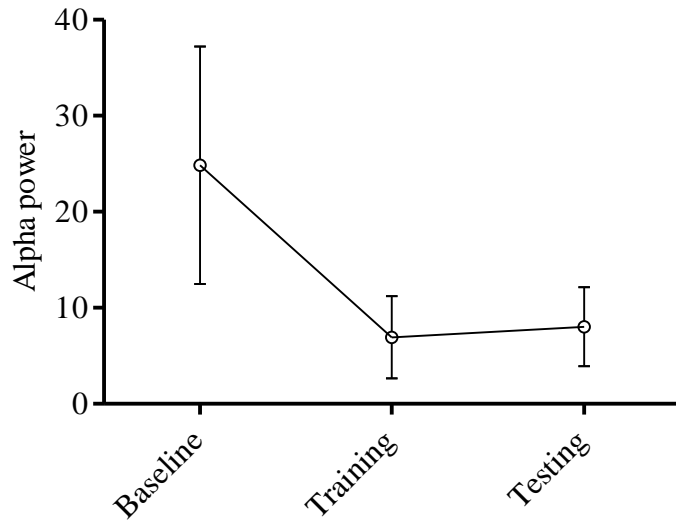


Figure 8. Grand average alpha power in μV^2 in all 9 regions during Baseline, Training and Testing in Experiment 1.1.

As can be seen in Figure 9 below, the largest changes in alpha power were observed in the Midline regions. Additionally, alpha power during Training was more similar across the nine regions than during Baseline or Testing.

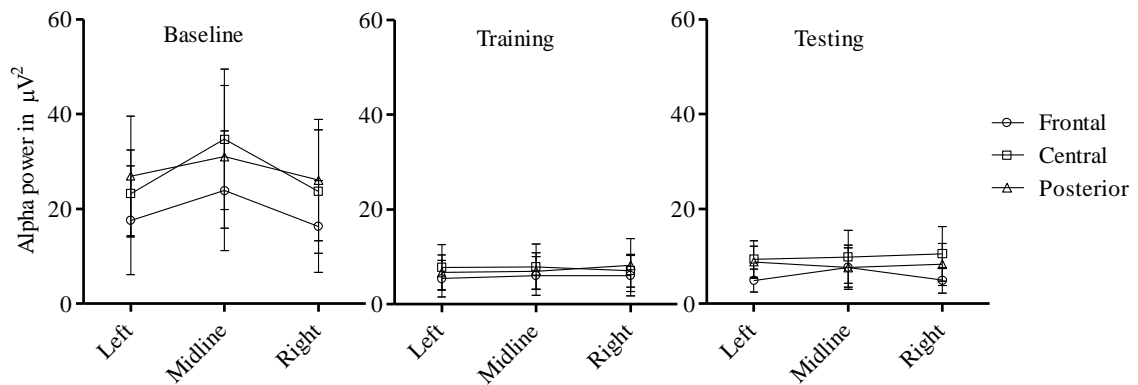


Figure 9. Average alpha power values and standard error in all 9 regions used for analysis during Baseline, Training and Testing in Experiment 1.1.

A large Coronal, ($F_{2, 14} = 33.212, p < .001, \eta_p^2 = .826$) and a medium Sagittal, ($F_{2, 14} = 7.992, p < .005, \eta_p^2 = .533$) effects were also found. A small Stage x Coronal, ($F_{4, 28} = 4.408,$

$p = .007$, $\eta_p^2 = .386$) interaction was found as well as a medium Stage x Sagittal, ($F_{4, 28} = 9.024$, $p < .001$, $\eta_p^2 = .563$) interaction. To further investigate these results, a one-way repeated measure ANOVA was performed on all nine regions. Following Holm-Bonferroni corrections (critical value of .0057), Stage had a significant effect on alpha power at all brain regions (see Table 3), although Mauchly's test of sphericity was violated for all but the Left-Central region.

Table 3.

Summary of F and p values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 1.1 at each of the brain regions for the alpha frequency.

Brain region	<u>Alpha (7.5-12 Hz)</u>			
	F	<i>p</i>	η_p^2	df
LF	11.820	.006*	.596	1.145, 9.161 ⁺
MF	15.916	.001*	.666	1.374, 10.994 ⁺
RF	11.665	.006*	.593	1.194, 9.549 ⁺
LC	22.251	.001*	.736	1.236, 9.89 ⁺
MC	26.817	<.001*	.770	1.193, 9.546 ⁺
RC	16.867	.002*	.678	1.122, 8.979 ⁺
LP	17.371	.003*	.685	1.042, 8.336 ⁺
MP	24.563	.001*	.754	1.055, 8.438 ⁺
RP	21.894	.001*	.732	1.113, 8.907 ⁺

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

*Significant effects following Holm-Bonferroni corrections

⁺ Greenhouse-Geisser correction

Similar to delta, the alpha frequency Stage effect can be attributed to differences between Baseline and Task conditions, but little or no difference between the two Task conditions. Pairwise corrected comparisons from the one-way repeated measures ANOVA revealed that Baseline alpha power was significantly higher than both Training and Testing at

all regions region (see Table 4) following Holm-Bonferroni corrections (critical value of .0057).

Table 4.

Summary of pairwise comparison p values between alpha power during Baseline and Training and Baseline and Testing in Experiment 1.1.

	<u>Power and p values</u>				
	<u>Baseline</u>	<u>Training</u>		<u>Testing</u>	
	Power	Power	p	Power	p
LF	17.52	5.40	.021*	4.91	.015*
MF	23.85	6.00	.007*	7.65	.008*
RF	17.42	6.08	.006*	4.89	.009*
LC	22.37	7.81	.002*	9.37	.007*
MC	36.74	7.93	<.001*	9.90	.001*
RC	24.02	7.11	.004*	10.54	.013*
LP	26.07	6.76	.005*	8.89	.014*
MP	32.53	7.01	.002*	7.69	.002*
RP	26.42	8.28	.003*	7.32	.004*

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

Note: All differences significant following Holm-Bonferroni corrections.

Discussion. Thirteen of 18 participants (72.2%) displayed Equivalence and twelve of those on the first exposure. Additionally, the one participant (Participant 11) that needed three exposures did not show gradual improvement in performance in the testing stages, but jumped from 1 out of 12 correct in the first two exposures to a perfect 12 out of 12 in the last exposure. None of the participants that failed to display equivalence displayed transitivity, but the relationship between performances in the two stages is not simple. Three of the 13 participants that displayed equivalence did not display transitivity. Using traditional criteria of equivalence acquisition, these participants would not have been considered as having displayed equivalence. However, when their performance is compared to the participants that

did not display equivalence, their performance differs significantly. Of the four participants that failed equivalence, none responded correctly to more than 4 trials in the Transitivity stage, whereas of the 3 that failed Transitivity and passed Equivalence correctly responded to 8, 9 and 10 trials out of 12 respectively.

The EEG results were similar to what had been expected. Overall delta power did increase significantly from Baseline to Task conditions. The differences observed can mostly be attributed to an overall increase in delta as a result of participants engaging in a cognitive task. Additionally, increases in the Mid-Central and posterior regions were most prominent as all effect size numbers were above .650.

Although theta power did show a visible increase between stages, this difference did not reach significance. When the individual regions were inspected separately, no significant differences were found in any single region.

As with delta, alpha power during the two task conditions was significantly different from Baseline. During both Training and Testing, the power of alpha was significantly lower than during Baseline, but no differences were found in overall alpha activity between the two task conditions. Similar to delta, the largest effect sizes were in the Posterior regions, but alpha additionally had medium effect sizes in the central regions. This finding was supported by the individual region results. In 8 of the 9 regions, Baseline alpha power was significantly higher than both Training and Testing, but no differences were found between the two task stages. In the Left-Frontal region, Baseline alpha power was only higher than Testing, indicating a possible role of Left-Frontal alpha during training.

Experiment 1.2

Readily nameable (or iconic) stimuli can facilitate equivalence responding due to the learning histories associated with those stimuli (see for example Arntzen, 2004). In Experiment 1.1, half of the participants demonstrated equivalence using such stimuli. The main aim of Experiment 1.2 was to explore differences in acquisition using abstract stimuli rather than the iconic stimuli used in Experiment 1.1. The protocol used in Experiment 1.2 was the same as in Experiment 1.1, a modified version of the protocol used by Dickins et al. (2001), except in the current experiment participants were trained using 6 three-member abstract stimuli in a multi-stage error-free training procedure. It was expected that participants would need a greater number of training trials in order to reach the mastery criterion in the conditional discrimination training stages. Additionally, a greater number of participants were expected to need repeated exposure to the experimental protocol. Delta and theta power during training was expected to be higher in participants in Experiment 1.2 than in Experiment 1.1 because of the increased difficulty of the task. However, alpha power was expected to be lower as the abstract images would require less naming/language related brain activity.

Method.

Participants. 20 healthy adult human (8 male) participants took part in the study. All participants were between 17 and 25 years of age, were right handed and had normal or corrected to normal eyesight; none reported taking psychotropic medication, or having sustained traumatic brain injury. All participants were first year students at the National University of Ireland Galway and participated as part of their course credit. The study was approved by the NUI Galway Research Ethics Committee.

Apparatus. Apparatus was the same as in Experiment 1.1.

Stimuli. The stimuli were grouped together in 6 3-member classes (A1-B1-C1, A2-B2-C2, A3-B3-C3, A4-B4-C4, A5-B5-C5 and A6-B6-C6). Alphanumeric labels refer to images used in the experiment (see Figure 10 for a depiction of all stimuli used along with their respective labels) but were not known to any of the participants.

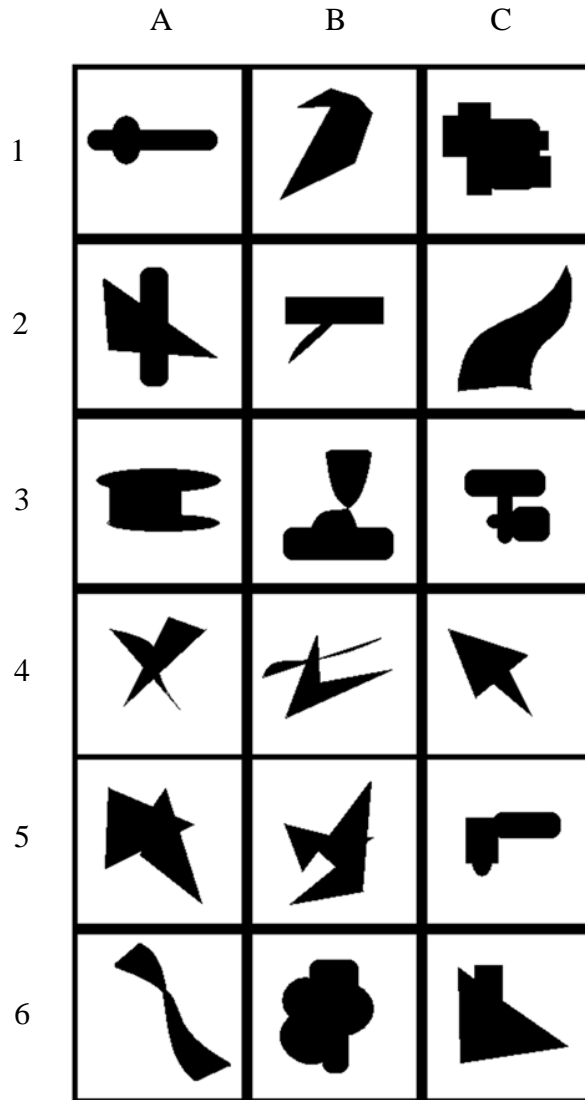


Figure 10. Stimuli used in Experiment 1.2, sorted by equivalence classes and alphanumeric denotations.

General procedure. Participant recruitment, demographic and handedness questionnaires and instructions were identical to Experiment 1.1.

EEG data preparation and analysis. EEG data preparation and analysis was identical to Experiment 1.1.

Conditional discrimination training and equivalence testing. The training and testing of the 6 three-member equivalence classes was identical to Experiment 1.

Results.

Behavioural results. Twenty participants (8 males) were recruited for the experiment. Participant 4 dropped out of the experiment after narrowly failing equivalence on the second exposure. This participant's data are not included in the final analysis. Eleven participants displayed equivalence and 8 did not. Of those eight, 5 were exposed to the protocol three times without displaying equivalence and 4 did not advance from training to testing. Results for the conditional discrimination training and testing and derived relational testing can be seen in Table 5 below. Of the 11 participants that displayed equivalence, 3 did so after a single exposure to the protocol, 5 after two exposures and 3 after three exposures. The 11 participants that displayed equivalence (Pass group) averaged 478.5 training trials, ranging from 159 to 700 trials. The 9 participants that did not display equivalence (Fail group) averaged 672.9 training trials, ranging from 494 to 808 trials. The overall pattern was that participants needed more exposures to A-B training than to B-C training, even on second or third exposures. During testing, participants performed well in Stage 4 (AB-BC testing), as 16 participants responded at criterion level. Results were similar in Stage 5 (symmetry), 16 (84.2%) participants performed to mastery criterion. Nine (47.4%) participants performed to mastery criterion in Stage 6 (transitivity). Of the remaining 10 participants, 6 were exposed to Stage 6 and 4 participants never advanced from training to testing. Only 4 participants in the Fail group were exposed to the protocol three times without displaying equivalence. This number was not sufficient to use as a comparison group and therefore EEG data from these participants were not analyzed.

Table 5.

Total number of trials during training stages and number of correct responses during testing stages in Experiment 1.2.

Participant	Training			Total	Testing			
	A-B	B-C	AB-BC		AB-BC	Symmetry	Transitivity	Equivalence
1	160	72	13	245	12/12	10/12	4/12	6/12
	72	72	12	156	12/12	11/12	3/12	2/12
	72	73	12	157	12/12	12/12	2/12	3/12
2*	329	330	48	707	----	----	----	----
3	73	74	12	159	12/12	11/12	11/12	12/12P
4	166	113	45	324	10/12	9/12	10/12	6/12
	73	85	12	170	12/12	12/12	11/12	10/12
5	195	73	22	290	11/12	10/12	8/12	8/12
	72	72	12	156	12/12	12/12	12/12	12/12P
6	91	73	13	177	11/12	12/12	11/12	11/12P
7	116	73	26	215	10/12	12/12	7/12	9/12
	72	72	13	157	12/12	12/12	12/12	11/12P
8	100	74	13	187	11/12	11/12	10/12	7/12
	72	72	12	156	12/12	12/12	12/12	12/12P
9	93	74	25	192	11/12	11/12	3/12	4/12
	73	74	12	159	12/12	11/12	2/12	10/12
	73	72	12	157	12/12	12/12	9/12	12/12P
10	79	72	30	181	12/12	12/12	5/12	2/12
	93	75	12	180	11/12	11/12	12/12	12/12P
11	80	73	13	166	11/12	10/12	8/12	7/12
	73	73	12	158	12/12	12/12	12/12	10/12
	72	73	12	157	12/12	11/12	11/12	12/12P
12*	688	46	----	734	----	----	----	----
13*	448	240	----	688	----	----	----	----
14	216	73	12	301	11/12	11/12	3/12	2/12
	73	72	13	158	12/12	11/12	3/12	3/12
	73	73	12	158	11/12	11/12	6/12	6/12
15*	228	549	----	777	----	----	----	----
16	264	82	13	359	12/12	8/12	2/12	1/12
	73	72	13	158	10/12	11/12	1/12	4/12
	72	72	12	156	11/12	8/12	2/12	1/12
17	184	74	12	270	12/12	12/12	7/12	9/12
	86	72	12	170	12/12	11/12	12/12	12/12P
18	122	72	12	206	12/12	11/12	11/12	11/12P
19	128	161	13	302	12/12	10/12	5/12	5/12
	83	109	13	205	12/12	11/12	9/12	9/12
	73	96	24	193	11/12	12/12	10/12	12/12P
20	127	221	26	374	10/12	12/12	6/12	7/12
	98	99	34	231	11/12	11/12	6/12	7/12
	104	87	12	203	11/12	11/12	6/12	9/12

* Training terminated after 80 min

EEG results. EEG data was analyzed for the 11 participants that displayed equivalence. Chosen for analysis were three points in the experimental stages; Eyes Closed Baseline, AB-BC mixed training and C-A equivalence testing. The experimental stages were chosen based on when participants displayed equivalence. For example, Participant 5 was exposed to the experimental protocol twice, and displayed equivalence on the second exposure. AB-BC training and C-A equivalence testing from the second exposure were then chosen for analysis for that participant (see Table 5). This was done to minimize variability within participants, as fatigue can have an effect on the EEG signal. The 32 electrodes were grouped into the same 9 regions as in Experiment 1.2 (see Figure 3). Because of variability of performance and trial numbers, no EEG data was analyzed for participants that did not display equivalence. Statistical analysis consisted of first a 3x3x3 (Stage x Front-Central-Posterior regions x Left-Mid-Right regions) repeated measures ANOVA on each of the frequency bands. If a significant effect was detected in the 3x3x3 ANOVA a one-way repeated measure ANOVA was then performed on each of the nine regions. Holm-Bonferroni corrections were applied to the p values (critical value .0056) of the one-way repeated measures ANOVAs. Additionally, all the regions were collapsed into one for a grand average measure by adding the region values together and dividing that number by nine. Holm-Bonferroni corrections were used on all pairwise comparisons (critical value .0167) within each individual region (differences between the experimental stages).

Delta (0.5 – 3.5 Hz). A 3x3x3 repeated measures ANOVA found a significant Stage effect, ($F_{2, 20} = 15.827, p < .001, \eta_p^2 = .613$), on delta power. Delta power during Baseline was $34.73 \mu V^2$, rose to $54.13 \mu V^2$ during Training and dropped to $46.32 \mu V^2$ during Testing (see Figure 11). This difference was significant both between Baseline and Training ($p = .002$) and Baseline and Testing ($p = .010$). However, no differences were found in overall delta power between Training and Testing ($p = .115$).

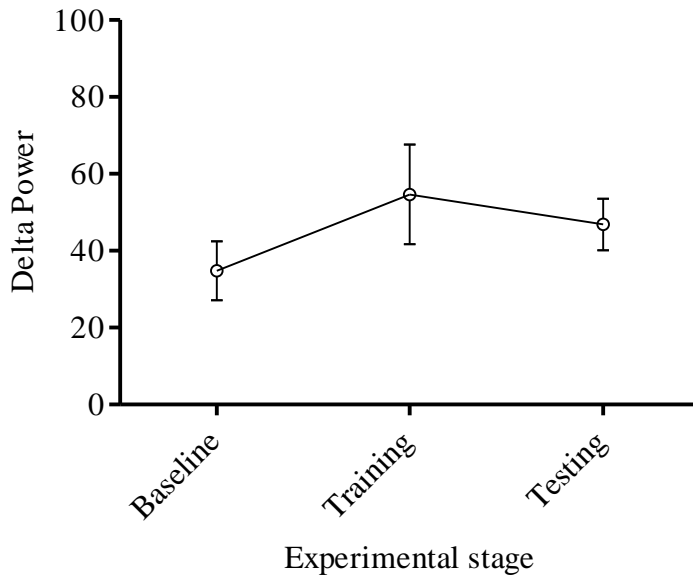


Figure 11. Grand average delta power in μV^2 during Baseline, Training and Testing in Experiment 1.2.

A one-way repeated measures ANOVA was performed on all of the nine regions to explore the effects of Stage on delta power. The increase in delta power from Baseline to the two Task conditions was most pronounced at Posterior regions (see Figure 12). A significant effect was found at all but three (Left-Frontal, Right-Frontal and Left-Central) regions (see Table 6 below).

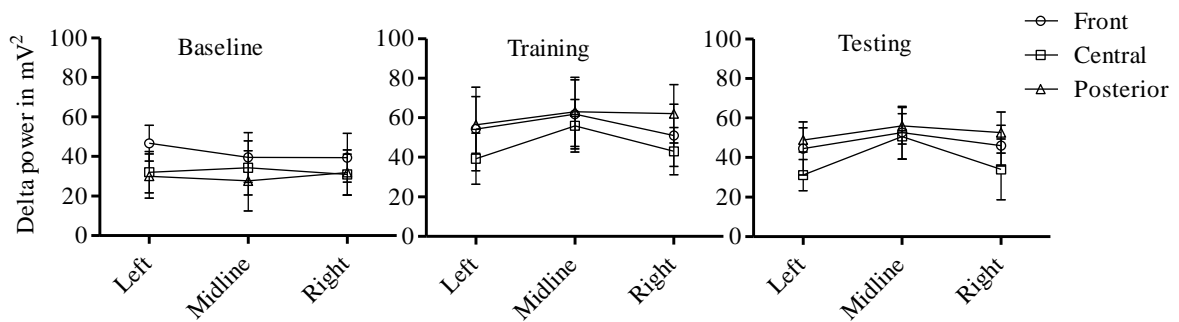


Figure 12. Delta power in μV^2 for all 9 regions used for analysis during Baseline, Training and Testing in Experiment 1.2.

Table 6.

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 1.2 at each of the brain regions for the delta frequency.

Delta (0.5-3.5 Hz)				
Brain region	F	p	η_p^2	df
LF	1.882	.178	.158	2, 20
MF	5.709	.011*	.363	2, 20
RF	3.318	.057	.249	2, 20
LC	2.502	.107	.200	2, 20
MC	8.991	.002*	.473	2, 20
RC	6.694	.006*	.401	2, 20
LP	20.736	<.001*	.675	2, 20
MP	18.159	<.001*	.645	2, 20
RP	21.547	<.001*	.683	2, 20

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

*Significant effect following Holm-Bonferroni corrections.

At the Mid-Frontal region, Baseline delta power was significantly higher than during Training ($p = .006$). No other differences were found at the Mid-Frontal region. At the Mid-Central region, Baseline delta power was significantly lower than Training ($p = .001$). Delta power at the Right-Central region was significantly lower during Baseline than during Training ($p = .006$). Baseline delta power at all posterior regions was significantly lower than delta power during Training and Testing (all p values $\leq .002$). No differences were found between Training and Testing at those locations.

Overall, the results for delta power are similar to those seen in Experiment 1 in terms of the distribution of effects as the Left-Frontal and Right-Frontal regions did not show any Stage effect. Additionally, the Left-Central region did not show any Stage effects. However, the effect sizes in Experiment 1.2 were lower than in Experiment 1.1. Differences between

stages at each individual region were assessed using Holm-Bonferroni corrections. The Mid-Frontal region showed a Stage effect and a significant difference was found between Baseline and Training but not between Baseline and Testing or between Training and Testing in that region.

No significant differences were found at the Right-Central region. At Mid-Central delta power during Baseline was significantly lower than Training ($p = .001$). At the Right-Central region, delta power during Training was significantly higher than during both Baseline ($p = .006$) and Testing ($p = .020$).

Baseline delta power was significantly lower than both Training and Testing at all Posterior regions ($p = < .002$ at all locations) but no differences were found between Training and Testing at those regions.

Overall, this pattern of effects could indicate that the changes in power are not due to any specific properties of the task, but rather a side effect of engaging in a cognitive task. The exception to that are the effects in the Right-Central area, where the Training task had significantly more of an effect on delta power than the Testing task.

Theta (3.5 – 7.5 Hz). A 3x3x3 repeated measures ANOVA did not show any Stage or Coronal effects. However a significant Sagittal, ($F_{2,20} = 11.086, p = .001, \eta_p^2 = .526$), effect was found. Additionally a Stage x Sagittal, ($F_{4,40} = 3.701, p = .012, \eta_p^2 = .270$), interaction was found. This lack of overall effect replicates that seen in Experiment 1.1, however, in this experiment it could be influenced by a large standard error in all three Stages (see Figure 13). Note there was a large variability in behavioural performance between participants.

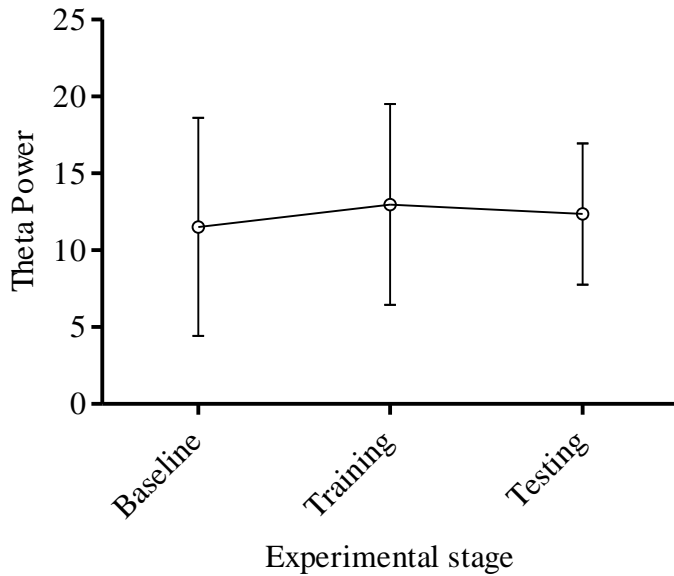


Figure 13. Grand average theta power in μV^2 during Baseline, Training and Testing in Experiment 1.2.

When individual regions were examined, the Posterior regions had a larger standard error than both Frontal and Central regions during Baseline. During Training, the greatest variability was in the Midline regions but during Testing no one region showed more variability than other (see Figure 14). Due to the lack of effects, no further analysis was conducted on the theta frequency.

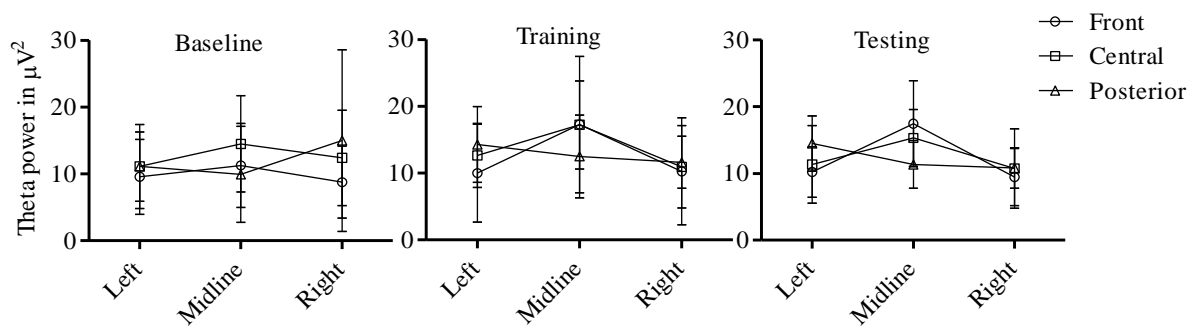


Figure 14. Theta power in μV^2 for all 9 regions used for analysis during Baseline, Training and Testing in Experiment 1.2.

Alpha (7.5 – 12 Hz). A 3 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed to assess any effects of Stage on alpha power on the Coronal and Sagittal planes. Mauchly's test indicated that the assumption of sphericity had been violated (chi-square = 11.315, $p = .003$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (epsilon = .583). The results show that Stage had a significant effect on alpha power, ($F_{1,166, 11.658} = 27.487, p < .001, \eta_p^2 = .733$). Baseline alpha power was significantly higher than both Training ($p < .001$) and Testing ($p < .001$). No significant differences were found in overall alpha power between Training and Testing (see Figure 15). Mauchly's test also indicated that the assumption of sphericity had been violated (chi-square = 10.397, $p = .006$) for Coronal effects. Therefore, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (epsilon = .593). The results show a Coronal effect, ($F_{1,187, 11.869} = 11.825, p = .004, \eta_p^2 = .542$) on alpha power as Frontal alpha power was significantly lower than both Central ($p = .004$) and Posterior ($p < .001$) alpha power.

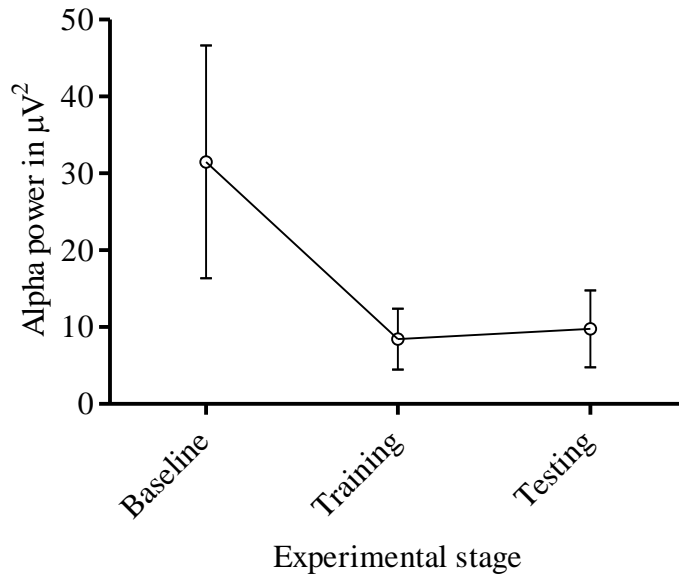


Figure 15. Grand average alpha power in μV^2 during Baseline, Training and Testing in Experiment 1.2.

A repeated measures one-way ANOVA was performed on each of the nine regions to assess any effects of Stage on alpha power. The results can be seen in Table 7 below.

Table 7.

Summary of F, p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 1.2 at each of the brain regions for the alpha frequency

Alpha (7.5-12 Hz)				
Brain region	F	p	η_p^2	df
LF	20.360	<.001*	.671	2, 20
MF	20.567	<.001*	.673	1.2, 12.0 ⁺
RF	16.110	.002*	.617	1.1, 11.1 ⁺
LC	12.653	<.001*	.559	2, 20
MC	22.041	<.001*	.688	2, 20
RC	17.149	.001*	.632	1.3, 12.7 ⁺
LP	31.533	<.001*	.759	1.1, 11.3 ⁺
MP	28.640	<.001*	.741	1.1, 11.1 ⁺
RP	24.069	<.001*	.706	1.1, 10.6 ⁺

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

⁺Greenhaus-Geisser correction

*Significant effect following Holm-Bonferroni corrections.

All nine regions displayed a strong Stage effect which can mostly be attributed to Baseline alpha power being significantly higher than alpha power during both Training and testing at all regions. No significant differences between Training and Testing were found at any of the nine regions. As can be seen in Figure 16, average alpha power at Frontal regions was significantly lower than at Central ($p = .001$) and Posterior ($p = <.001$) regions as expected.

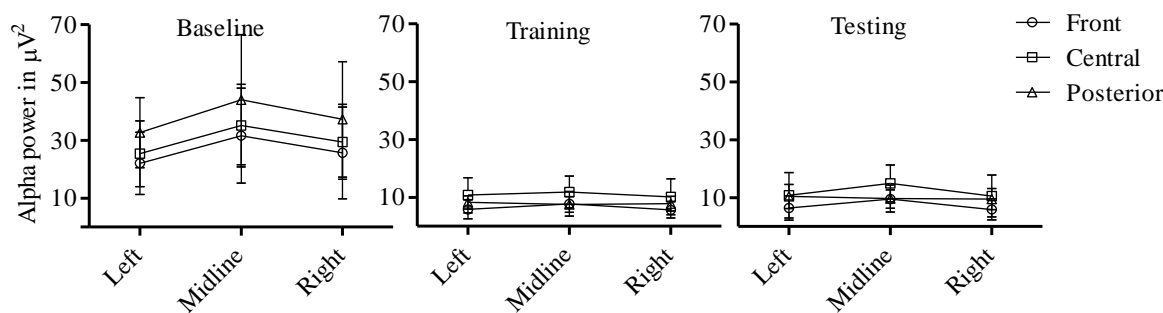


Figure 16. Alpha power in μV^2 for all 9 regions used for analysis during Baseline, Training and Testing in Experiment 1.2.

Discussion. In Experiment 1.2, only 3 participants displayed equivalence after one exposure, 5 after two exposures and 3 after three exposures, bringing the total number of Pass participants to 11 (58%). The behavioural results from Experiments 1.1 and 1.2 indicate that although participants can be trained to display equivalence with both iconic and abstract stimuli, the amount of training needed varies to a great degree. In Experiment 1.1, 12 of the 17 recruited participants displayed equivalence after only one exposure. One participant needed 3 exposures in order to display equivalence, bringing the total number of Pass participants to 13 (76.5%) in Experiment 1.1.

Participants in both Experiment 1.1 and 1.2 were trained to demonstrate a series of related conditional discriminations, and the results confirm the predictions that iconic stimuli are more conducive to the formation of derived responding as a greater number of participants displayed equivalence in Experiment 1.1 than Experiment 1.2. Additionally, participants in Experiment 1.1 needed fewer trials to reach the mastery criterion than the participants in Experiment 1.2. This confirms the results from Holth & Arntzen (1998), Arntzen (2004) and Benthall, Dickins & Fox (1993) that iconic and easily nameable stimuli facilitate equivalence class formation and derived responding.

In the current study, participants required more training trials to achieve the mastery criterion of 11 out of 12 correct answers, when abstract stimuli were employed than when iconic stimuli were employed. This outcome is similar to the results obtained by Bentall, Dickins & Fox (1994) where participants exposed to abstract stimuli needed more training trials to display equivalence. In Experiment 1.1, iconic stimuli were employed and 15 out of the 18 (83.3%) participants demonstrated equivalence in their first equivalence test, but, when abstract stimuli were employed in Experiment 1.2, only 2 out of 20 (10%) demonstrated equivalence when first assessed. However, the response patterns in the two experiments were somewhat different. Most participants in Experiment 1.1 (14 out of the 18) needed less than 100 trials to reach mastery criterion in the initial exposure to the A-B stage. However, only 5 of the 20 participants in Experiment 1.2 reached mastery criterion in fewer than 100 trials. However, all of the 12 participants that were exposed to the protocol two or more times needed fewer than 100 trials on the second exposure. If the differences in A-B training were due to participants in Experiment 1.2 having a difficulty naming and organizing the abstract stimuli, one would assume that this group difference would still be evident in the B-C training stage when they were presented with more abstract stimuli. However that was not the case, as the difference between response patterns displayed in the two experiments all but disappeared in the B-C training stage. In Experiment 1.1 only one participant needed more than 75 trials to master the B-C connections. Of the 16 participants that did not time out during training in Experiment 1.2, only two needed 80 or more trials to reach mastery criterion.

All participants in both experiments displayed Symmetry. The participants in Experiment 1.1 all displayed Symmetry on the first exposure, but participants in Experiment 1.2 displayed Symmetry on either the first or second exposure. Ten participants in each experiment displayed Transitivity and 13 participants displayed Equivalence in Experiment

1.1 and 10 participants displayed Equivalence in Experiment 1.2. When comparing the stages where derived relations were tested, very few differences were found between the experiments in the test for Symmetry as all participants in both experiments displayed Symmetry. There is some evidence to suggest that symmetry is more likely to be observed than other derived relations, because the A-B and B-C stimulus pairs had already been presented together during the training stages (see for example Dickins & Dickins, 2001).

Interestingly, both groups performed better during the Equivalence test stage than during the Transitivity test stage. In Experiment 1.1, 10 participants displayed Transitivity but 12 displayed Equivalence. In Experiment 1.2, 8 participants displayed Transitivity and 10 displayed Equivalence. The C-A Equivalence test is considered to be a combined Symmetry and Transitivity test and it would be expected to be more difficult for participants than either of the previous tests. If this response pattern can be considered Delayed Emergence of stimulus equivalence, it is different than in previous research as it is evident in both abstract and iconic groups but previous research has only found this response pattern in participants exposed to iconic stimuli (Holth & Arntzen, 1998).

The only noteworthy EEG effect in Experiment 1.2 were found in the delta frequency, where delta power during Baseline was significantly lower than during both Training and Testing in the Mid-Frontal, Mid-Central, Right-Central and all Posterior regions, the same regions as in Experiment 1.1. Additionally, the largest effect sizes were again found in the posterior regions. However, delta power during long experimental tasks or long periods of concentration can increase (Rowan & Tolunsky, 2003) due to fatigue. Thus, the difference in the number of exposures to the protocol raises a question when it comes to comparing EEG activity in Pass participants in the two experiments. Any differences found between the Experiments would have to be interpreted with utmost caution as they might be due to fatigue rather than the stimuli used in the experiments. However, both experiments employed the

same protocol which was intended to train equivalence relations which could indicate that delta plays a role in equivalence relations. To ascertain this, a number of issues need to be addressed. First, the EEG measurements in the two experiments were not taken after the same amount of exposure time. As the EEG is affected by fatigue in participants, this could alter the strength of the delta response, especially in participants that were exposed three times to the protocol. Second, more measures need to be taken during the experimental task, to allow for multiple comparisons during the time in which the participants are engaged in cognitive activity. Overall, this pattern of effects could indicate that the changes in power are not due to any specific properties of the task, but rather a side effect of engaging in a cognitive task. The exception to that are the effects in the Right-Central area, where the Training task had a significantly more effect on delta power than the Testing task.

The stage effect found in the alpha frequency was only attributed to alpha power differences between baseline on one hand and the two task stages on the other hand. No significant differences were found between the two task stages. The lack of effect in the alpha frequency was unexpected, as alpha has been linked with cognitive effort and performance. However, alpha is also very sensitive to shifts in attention and concentration which could have changed during the course of Experiment 1.2 in participants that were exposed multiple times to the protocol. As in Experiment 1.1, no effects were found in the theta frequency in Experiment 1.2.

No difference was found in the theta frequency in Experiment 1.2. Based on the results from Experiment 1.1 this was not unexpected. However, due to the nature of the equivalence task an effect could be found in that frequency with a changed protocol.

As mentioned earlier, the experimental protocol employed in the current study was a variation of that employed in an fMRI study by Dickins et al. (2001). During the course of these two experiments, a number of features of this paradigm were found to be less suitable

for EEG research than for fMRI research. First, only 12 trials could be used in each stage of the experiment. This is a low number of trials for an EEG experiment. EEG data are notoriously noisy (Rowan & Tolunsky, 2003). The electrical potentials generated by neurons are blocked, diffused and corrupted by the layers of brain, fluid, bone and scalp that they must pass through before being recorded at the scalp. It is therefore necessary to have a large number of trials in order to facilitate identifying a reliable signal in this noise. This may, in part, explain the large standard error in theta band activity in Experiments 1.1 and 1.2 and alpha band activity observed in Experiment 1.1, and this increased variation may have contributed to the lack of effects observed in those frequency bands.

Another potential problem, albeit not encountered in Experiment 1.2, is the possibility of very different response patterns for participants that display equivalence. Participant 11 in Experiment 1.1 is an example of this response pattern, needing 3 exposures to display equivalence. Because other participants that displayed equivalence only needed one exposure, it is hard to justify comparing Participant 11 to them as EEG power is known to decrease with time. If the goal was to use baseline power to predict performance, the same problem arises. Do we only include participants that needed more than one exposure to the protocol as members of the Pass group, or do we include them in the Fail group? Another question not answered here is if there is a difference between the Pass and the Fail group during training. In other words, can we use the EEG to predict performance on the stimulus equivalence task? The current protocol does not allow that, as too many participants displayed equivalence. The number of stimuli presented could also be a potential problem, as the sample comparison was presented at the top of the screen and up to six comparisons were presented at the bottom. This could induce substantial eye movement, making any speculation about the role of gamma waves difficult as they are most seriously affected of all waves by eye movement artefacts. Lastly, this experimental session could last up to 2 ½ hours, with breaks, if

participants were exposed to the protocol 3 times as each exposure could take 40 minutes and preparation time was usually 30 minutes. This increases the likelihood of fatigue effects in the EEG, especially an increase in delta power and a rise in alpha power as time passes.

Chapter 3: Study 2

Experiment 2.1

Experiments 2.1 and 2.2 sought to rectify some of the problems encountered in Experiments 1.1 and 1.2 by improving the experimental protocol but using the same stimuli as were previously employed. In Experiment 2.1 the stimuli used were the first three stimulus classes used in Experiment 1.1 and by Dickins et al. (2001). The improvement in the protocol design would allow a better investigation of the delayed emergence of equivalence and of the differences in learning patterns between participants exposed to abstract and iconic stimuli. Additionally, the increase in trials and changes in experimental setup (described below) would increase the quality of the EEG signal, allowing for the analysis of both beta and gamma frequencies.

First, each A-B and B-C training stage now had a set limit of 54 trials each. This way, all participants would be exposed to the same amount of trials and be on 'equal footing' when they were exposed to the testing stages. The participants were taught three equivalence classes instead of six in the previous experiments. Although this change in protocol might seem to make the task substantially easier for the participants than the previous experiment, this should not be the case. Arntzen & Holth (2000) compared the effects of number of classes and class size on acquisition of equivalence relations in two experiments. In the first experiment 50 participants were split into 10 groups and the number of equivalence classes and members in each class were systematically varied. The groups were exposed to 3 to 6 equivalence classes and the number of members in each class was between 3 and 6. The stimuli used as 'B' stimuli were always iconic or easy to name pictures, but other stimuli were either Greek or Arabic letters or abstract symbols. Their results show that the critical variable was not the number of equivalence classes but the number of members in each class. In light of these results, the decrease in the number of classes used in Experiments 2.1 and 2.2

was not considered to be an important factor. However, it must be noted that Arntzen & Holth (2000) did use a mastery criterion for their participants, which was not done in the present experiments.

Second, participants were only exposed to the protocol once, potentially splitting the sample into two clear groups, Pass or Fail, without having to judge whether participants displaying equivalence on different exposures should belong in the same experimental group. Additionally, participants that differ greatly in the number of trials needed to display equivalence should not be treated the same as their learning histories are quite different once the equivalence testing commences.

To further investigate if exposure to Transitivity can influence outcome on Equivalence tests, as seemed to be the case in Experiments 1.1 and 1.2, the Equivalence test was conducted first, before tests of Transitivity and Symmetry respectfully. Previous research (Arntzen & Holth, 1997) has indicated that testing for Symmetry before Equivalence does not influence Equivalence test outcomes significantly. However, the authors did not investigate if Transitivity affected the outcomes of the Equivalence test. Given that more participants displayed Equivalence than Transitivity in both Experiments 1.1 and 1.2, the order of testing might influence the outcomes. If that is the case, then more participants should display Transitivity than Equivalence in the current test set up. Additionally, this testing procedure would decrease fatigue effects in the EEG during Equivalence testing, which is the testing stage of most interest in the current study. Another change in the protocol is the presentation of the sample and comparison stimuli separately, thereby minimizing eye movement artefacts.

Holth & Arntzen (1998) discuss the idea of delayed emergence of stimulus equivalence, that is, when participants display equivalence on the latter stages of equivalence testing but not on the early stages. In Holth & Arntzen (1998), the equivalence test consisted

of 12 trials and delayed equivalence was said to have occurred if participants did not display equivalence on the first 6 trials but did so on the last six. As noted earlier, no participant in either Experiment 1.1 or 1.2 displayed this type of response pattern during the test stages. However, it can be argued that defining delayed emergence by performance in only two blocks might be insufficient. Individual performances often vary considerably within a single block of trials. Therefore, having only two blocks (or data points) might not give an accurate picture of the increase in performance by participants. Having three or more trial blocks, or a rolling average, might be more accurate. In the protocol employed in Study 2, seven of the eight stages have at least three trial blocks. This way, it is easier to ascertain if improvements in performance are due to short term fluctuations or a truly improving performance.

EEG analysis was largely identical to Experiment 1.1, except beta and gamma frequencies were added to the analysis. Because of large power fluctuations in the beta and especially gamma frequencies, the increased number of trials makes it possible to include those frequencies and at the same time reduce errors in the EEG measurements. Even though the gamma frequency is defined as being between anywhere between 30 and 100 Hz, evidence does suggest that the most functionally relevant activity for memory and categorization is somewhere near the 40 Hz range (Barry, Clarke, Hajos, McCarthy, Selikowitz & Dupuy, 2010; Herrmann, 2003; Herrmann & Mecklinger, 2001).

Brzezicka, Kaminski, Kaminski and Blinowska (2011) investigated EEG activity during transitive reasoning ($A > B, B > C = A > C$). When stimuli in reasoning tasks were nonspecific or lacked conceptual content, activity was increased in the right prefrontal and the bilateral parietal cortex. The researchers compared activity at 20 electrode sites during a simple memory recognition task to a transitive reasoning task. The results showed that in the theta frequency, levels of activity at the Fz electrode (located in the Mid-Frontal region in the current setup) were higher during the transitivity task than during the memory task. This

would roughly correlate to increased activity in the Mid-Frontal region in the current study. Alpha activity was also increased at the Fz and F3 electrodes during the transitivity task, but decreased at the F4 and C4 electrodes. Results in the gamma frequency displayed a more dynamic response pattern. Activity at the Fz electrode and the surrounding areas decreased during the transitive reasoning test when compared to the memory test. However, activity at the P8 electrode (Right-Posterior region) and surrounding areas increased during the transitive reasoning test. Additionally, overall gamma activity on the left side was less pronounced than on the right side during the latter.

Another notable feature of the gamma response is its differential response to familiar and unfamiliar words (Herrmann, Fründ & Lenz, 2010). When participants in a memory experiment encounter stimuli that are familiar to them ('have an existing memory representation for' p. 983) the gamma band response is larger than to stimuli that are not familiar or have not been observed before. In the current experiment, this would mean that gamma responses to the iconic images should be larger than for abstract images, specifically in the initial A-B training stages. However, as the participants become more familiar with the abstract stimuli, these differences should decrease. However, due to the long learning history that most participants will have with iconic imagery, it is unlikely that this difference will completely disappear, even with continuous training.

Goel, Stollstorff, Nakic, Knutson & Grafman (2009) argue that bilateral activity in the ventrolateral prefrontal cortex (VLPFC) is due to participants trying to decipher indeterminate relations. Another variable that can activate the VLPFC is if the problems/tasks shown to participants are unfamiliar or nonspecific. Unfamiliar tasks are for example when participants have to determine if statements such as "A=B; B=C -> A=C" are correct. When such a statement or task is presented to participants, they show bilateral activity in the VLPFC. When the problem/task is presented involving things participants have beliefs or

prior knowledge about, such as “All cats are mammals, mammals are animals, all cats are animals”, the activity is more pronounced in the left VLPFC. However, if the latter problem involves a conflict (either logical or against the participants belief), the activation is mostly in the right VLPFC. When it comes to trained derived relations and brain activity during testing, this activity might be expected to be bilateral in frontal areas in participants that have not acquired the derived relations (see for example Dickins et al., 2001), but more concentrated in the Left-Frontal areas in participants that display equivalence.

Baseline EEG activity has been shown to correlate with performance on a multitude of cognitive and language tasks (see Introduction for a full review). However, most of those baseline differences were found in the alpha or theta frequency range. With the possible involvement of gamma in cognitive, language and attention tasks (see for example Fründ & Herrmann, 2007) it is likely that differences can be found in gamma power during baseline. Barry et al. (2010) found that children with AD/HD had lower gamma power in posterior regions during eyes closed and Benasich, Gou, Choudhury & Harris (2008) found that gamma power in frontal areas during an eyes open period was positively correlated with higher scores for language and cognitive function.

Method.

Participants. Seventeen healthy adult human (4 male) participants took part in the study. All participants were between 17 and 20 years of age, were right handed and had normal or corrected to normal eyesight; none reported taking psychotropic medication, or having sustained traumatic brain injury. All participants were first year students at the National University of Ireland Galway and participated as part of their course credit. The study was approved by the NUI Galway Research Ethics Committee.

Apparatus. Training and testing involved a PC computer with E-Prime 2.0.8 software for stimulus presentation and recording of behavioural data. The stimuli were presented on a

Compaq S716 16' monitor using a Windows 98 operating system. Silver/silver-chloride (Ag/AgCl) recessed ring electrodes were used for EEG recording. All electrodes cables were individually shielded (ActiShield_{TM}) and all channels were amplified against the average of all connected inputs. A Quick-Amp 40 EEG amplifier (Brain Products) was used with BrainVision Recorder (v. 2.0) and BrainVision Analyzer (v. 2.0.1.3417) software (Brain Products). Sampling rate was 1000 Hz during recording and changed to 1024 during analysis to adhere to the requirements of FFT, and frequencies between 0.5 and 40 Hz were used for analysis (delta 0.5-3.5, theta 3.5-7.5, alpha 7.5-12, beta 12-20, l-gamma 30-40 and h-gamma 60-80 Hz). Vertical (VEOG) and horizontal (HEOG) electro-oculogram activity were recorded to control for eye blink artefacts. Following offline ocular correction, artefact free 2 second epochs during baseline and around correct and incorrect responses during AB Training, BC Extinction and Equivalence were selected for analysis.

Stimuli. The stimuli were grouped together in classes of A1-B1-C1, A2-B2-C2 and A3-B3-C3. The alphanumeric labels refer to images used in the experiment but were not known to any of the participants. The stimuli used were the first three iconic stimulus classes from Experiment 1.1 (see Figure 1).

General procedure. Participant recruitment was identical to previous experiments (see p. 22 for details). Handedness was now assessed using the Edinburgh Handedness Inventory (see Appendix 2). Participants were then seated in the experimental cubicle and prepared for the EEG recording. Following preparation, participants were instructed to sit comfortably with their eyes closed for 5 minutes and for 5 minutes with their eyes closed. The purpose of the 5 minute eyes closed period was to obtain a baseline for FFT analysis. Following this baseline period, participants were exposed to the five stages of conditional discrimination training part of the experiment followed by the three stages of testing of derived relations (see Figure 17 below). No minimum correct criterion was required at any

stage of the Experiment so participants advanced to the next stage irrespective of performance. After finishing the last Stage (B-A/C-B testing) the experiment was terminated and participants were not re-exposed to the experiment if they had performed poorly.

Stage one: AB training

54 trials (18 x A1-B1, 18 x A2-B2, 18 x A3-B3)

Stage two: AB extinction

54 trials (18 x A1-B1, 18 x A2-B2, 18 x A3-B3)

Stage three: BC training

54 trials (18 x B1-C1, 18 x B2-C2, 18 x B3-C3)

Stage four: BC extinction

54 trials (18 x B1-C1, 18 x B2-C2, 18 x B3-C3)

Stage five: AB/BC training

36 trials (12 x A1-B1, 12 x A2-B2, 12 x A3-B3, 12 x B1-C1, 12 x B2-C2, 12 x B3-C3)

Stage six: CA Equivalence testing

54 trials (18 x C1-A1, 18 x C2-A2, 18 x C3-A3)

Stage seven: AC Transitivity testing

54 trials (18 x A1-C1, 18 x A2-C2, 18 x A3-C3)

Stage eight: BA/CB Symmetry testing

108 trials (18 x B1-A1, 18 x B2-A2, 18 x B3-A3, 18 x C1-B1, 18 x C2-B2, 18 x C3-B3)

Figure 17. Schematic outline of Experiment 2.1.

EEG data preparation and analysis. EEG data preparation and analysis was identical to previous experiments (see description on p. 28) with the exception of a software upgrade and the addition of beta (12-30 Hz) and gamma (30-40 Hz) waves to the analysis.

Impedances were assessed using BrainVision Recorder (v. 2.0) software (Brain Products,

GmbH, München, Germany) and were kept below 5 k Ω . A QuickAmp 40 EEG amplifier (Brain Products, GmbH, München, Germany) was used in conjunction with BrainVision Recorder and BrainVision Analyser (v. 2.0.1.3417) software (Brain Products, GmbH, München, Germany). The experimental stages chosen for analysis were Baseline, AB Training, BC Extinction and Equivalence. The reasons for choosing different stages than in the previous experiments are the following: first, analyzing AB Training will give a glimpse of EEG activity at the very beginning of equivalence training, when EEG activity should be most significantly different from Baseline. Second, BC Extinction will allow us to gauge EEG activity when participants are engaged in a task that they are well fluent in. Additionally, any possible feedback artefacts will be absent during an extinction period.

Conditional discrimination training. Conditional discriminations, necessary for the formation of the three three-member equivalence classes in the task, were trained using a delayed matching to sample (MTS) linear protocol in five stages. Stages 1 through 4 had 54 trials and Stage 5 had 36 Trials. In Stage 1 the following conditional discriminations were trained: A1 \rightarrow B1, A2 \rightarrow B2 and A3 \rightarrow B3. In the first trial in Stage 1, a focus cross was presented for 500 ms at the centre of the screen, followed by one A stimulus which was presented for 1000 ms. The A stimulus was then replaced by three B stimuli, one of which was the correct comparison. The location of the correct and incorrect B stimuli was randomly counterbalanced. Participants chose the comparison by pressing the ‘1’, ‘2’ or ‘3’ buttons on the number pad on the keyboard. ‘1’ corresponded to the B stimulus on the left, ‘2’ corresponded to the B stimulus in the middle and ‘3’ corresponded to the B stimulus on the right. Following their response, feedback, either ‘Correct’ or ‘Incorrect’ was presented in 48 pt. Times new roman font at the centre of the screen for 1000 ms followed by the focus cross which signalled the start of the next trial. Stage 2 was identical to Stage 1, except no feedback was given to participants on their performance. Instead of a feedback, a blank screen was

presented for 1000 ms, followed by a focus cross. In Stage 3, a focus cross was presented for 500 ms, followed by a single B stimulus for 1000 ms. The B stimulus was then replaced with three C stimuli. Participants chose the stimuli in the same manner as in Stage 1 and feedback was given in the same manner as in Stage 1. Stage 4 was identical to Stage 2, except B stimuli were used as samples and C stimuli as comparisons. No feedback was provided for performance in Stage 4. Stage 5 was a mixed extinction stage where A-B and B-C pairs were randomly presented in the same manner as in previous stages.

Testing derived relations. All testing stages were designed with the same parameters as Stages 2 and 4 in the Conditional discrimination training with regards to timing and inter stimulus interval. Stage 6 was a mixed testing block, consisting of 54 trials which tested all equivalence relations ($C1 \rightarrow A1$, $C2 \rightarrow A2$ and $C3 \rightarrow A3$). Stage 7 was a mixed testing block, consisting of 54 trials which tested all transitive relations ($A1 \rightarrow C1$, $A2 \rightarrow C2$ and $A3 \rightarrow C3$). Finally, Stage 8 was a mixed testing block, consisting of 108 trials which tested all symmetrical relations ($B1 \rightarrow A1$, $B2 \rightarrow A2$, $B3 \rightarrow A3$, $C1 \rightarrow B1$, $C2 \rightarrow B2$ and $C3 \rightarrow B3$).

Results.

Behavioural results. Seventeen participants were recruited for the experiment, 10 participants displayed equivalence during the C-A (Equivalence) stage. Participants that scored 88% correct (48 out of 54 trials) or higher in Equivalence were considered to have passed the equivalence test. The participants were assigned to one of two groups, Pass and Fail, based on their performance during Equivalence. This 88% mastery criterion was used to determine participants' performance in all stages of the experiment. Percentage of correct responses for all 17 participants during all 8 stages of the experiment can be seen in Table 8 below.

Table 8.

Percentage of correct responses during training and testing stages in Experiment 2.1

	AB Train	AB Ext	BC Train	BC Ext	ABBC Train	CA	AC	BA/CB
1	59.26	100.00	88.89	100.00	91.67	92.59	98.15	91.67
2	85.18	94.44	70.37	96.29	86.11	18.52	5.56	91.67
3	83.33	94.44	92.59	98.15	94.45	98.15	100.00	94.44
4	72.22	100.00	81.48	100.00	97.22	100.00	100.00	99.07
5	85.18	92.59	85.18	98.15	100.00	35.18	37.04	96.29
6	42.59	33.33	87.04	100.00	94.45	37.04	35.18	79.63
7	90.74	98.15	88.89	94.44	100.00	88.89	33.33	40.74
8	64.81	75.93	83.33	100.00	97.22	37.04	33.33	75.00
9	24.07	24.08	61.11	85.19	91.67	29.63	36.96	59.26
10	38.89	50.00	70.37	90.74	91.67	90.74	87.04	88.89
11	92.59	98.15	98.15	100.00	91.67	100.00	100.00	93.52
12	92.59	98.15	90.74	98.15	97.22	98.15	100.00	100.00
13	81.48	98.15	92.59	94.44	83.34	94.44	98.15	95.37
14	46.30	77.78	85.19	96.29	94.45	72.22	90.74	90.74
15	75.92	96.30	90.74	96.29	97.22	94.44	90.74	94.44
16	90.74	100.00	96.30	98.15	100.00	98.15	100.00	99.07
17	79.63	98.15	85.18	96.30	88.89	38.89	33.33	49.07

Note: Performance above the 88% mastery criterion in boldface

Only 4 participants scored higher than the 88% criterion in the AB training stage, but scores ranged from 24.07 to 92.59 percent. Little relation was found between training performance and subsequent display of equivalence (see Figure 17). Participants that displayed equivalence scored between 38.89 and 92.59 percent in AB training, with an average of 77.78 %, and participants that failed to display equivalence had an average of 61.11 percent. During AB extinction, the Pass groups' performance improved to 93.33 %, with a range from 50 to 100%, and the Fail groups' performance improved to 70.90%, with a range from 24.08 to 98.15 percent.

The difference between the two groups decreased during BC training, 89.07 % for the Pass and 79.63% for the Fail, as performance in the Pass groups dropped slightly from the previous stage while the Fail groups' performance continued to improve. During the last two training stages, BC extinction and AB/BC training, performance in the two groups was almost identical. The average score for the Pass group during BC extinction was 97.04% but

96.03% for the Fail group, and 94.45% for the Pass group during AB/BC but 93.23% for the Fail group.

A clear difference in performance could be seen between the groups during both Equivalence and Transitivity test stages. The Pass groups' average score during Equivalence was 95.56%, while the Fail groups' average was 38.27 percent. Included in the Fail groups' average were the scores from Participant 14, who did not display equivalence, but whose score was noticeably higher (72.22%) than the second highest in that group (38.89%). If Participant 14 was excluded from the analysis, the Fail groups' score decreases to 31.48%.

During Transitivity, the Pass groups' average was 90.74% but the Fail groups' average was 39.8 percent. However, two participants' data decreased the differences between the groups. Participant 7 only scored 33.33% in the Transitivity testing, the only member of the Pass group not to display Transitivity, but the second lowest score in the Pass group was 87.04 percent. Participant 14 again stood out of the Fail group, scoring 90.74% during Transitivity, but the second highest score in that group was 37.04 percent. If these two participants were removed from the analysis, the Pass groups' average increased to 97.12% and the Fail groups' average dropped to 29.61 percent..

The groups' scores were more similar for Symmetry testing than in the previous two testing stages. The Pass group averaged 89.72% correct, but the Fail group averaged 77.38% correct responses for Symmetry. Again, these differences were increased if Participant 7 and Participant 14 are removed from the dataset. Then the average for the Pass group increases to 95.16% and the Fail group dropped to 75.15 percent. Despite the increased difference between the groups after excluding these two participants, this testing stage did not differentiate between the two groups as well as the previous two testing stages.

Participants 7 and 14 stood out in terms of performance during the first two test stages. Participant 7 displayed equivalence (88.89% correct) during Equivalence, but his

performance dropped below the criterion during Transitivity (33.33% correct) and Symmetry (40.74% correct). Participant 14 showed the opposite pattern, did not display equivalence (72.22%) but performed above criterion during both Transitivity and Symmetry (90.74% correct in both).

The performance of the two groups was distinctive throughout the experiment (see Figure 18) as overall performance was lower for the Fail group in 6 of the 8 stages of the experiment.

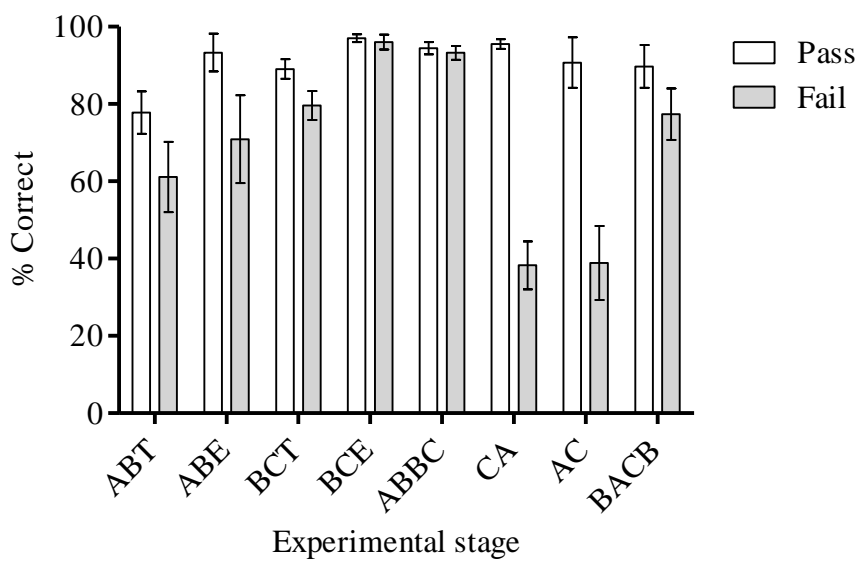


Figure 18. Average performance and standard error during all stages of Experiment 2.1 for both Pass and Fail groups.

Apart from Equivalence and Transitivity, the greatest difference between the two groups was during A-B Training and Extinction. This could indicate that performance during initial training can be used to predict performance on the Equivalence task. It is also noteworthy that the Fail group's performance improved during training. In the final two stages of training, the two groups were virtually indistinguishable, both having mastered the conditional discriminations.

When inspected individually, 13 of the 17 participants reached the mastery criterion in the last block of AB Training (see Table 9 below). Only Participants 6, 8, 9 and 10 did not reach the mastery criterion in any of the training blocks. However, Participant 8 did show a steady improvement in performance, going from 50% in the first block, to 61.11% in the second and finally to 83.33% correct in the third block. During the AB Extinction stage, 12 of the 17 participants reached the mastery criterion. Additionally, all of those 12 participants had shown delayed learning in the AB Training stage. The one participant that did not reach the mastery criterion in the AB Extinction stage, but did display delayed learning in the AB Training stage, Participant 14, did again show delayed learning during the AB Extinction stage. In the first Extinction block he scored 50% correct, in the second one 83.33% correct and finally 100% correct in the third and last extinction block. Of the four participants that did not reach the mastery criterion in the previous stage, numbers 6, 8, 9 and 10, three (6, 9 and 10) did not reach the mastery criterion in the AB Extinction stage. P8, whose performance did improve during the AB Training stage, did show an improvement in the AB Extinction stage. During the first two blocks his performance was 66.67% correct but improved to 94.44% in the last block.

The performance during BC Training was similar to AB Training, although the Fail groups' performance did improve and no participant in the experiment showed less than 61% overall accuracy. However, all the participants did show a delayed learning effect and all but one (Participant 10) reaching the mastery criterion in the last block of BC Training. It is worth noting though, that even that participant did show a slight improvement in performance, going from 55.56% in the first block to 77.78% correct in the last two.

No differences were observed between the groups during the last two training stages of the experiment, with less than 2% difference between the groups in each stage respectively. During BC Extinction Participant 9 was the only one not to reach the mastery

criterion. However, he did reach the mastery criterion in the first and third blocks of BC Extinction, but not during the second block. This reduced his average score below the mastery criterion. No noticeable differences were observed between the two groups during the AB/BC Mixed Training. Of the 34 combined blocks of all the participants in the AB/BC stage, only three blocks were below the mastery criterion. Participant 2 scored 88.89% correct in the first block of AB/BC Mixed Training but dropped slightly down to 83.33% in the second block. This was enough to decrease the average performance to below the mastery criterion. Participant 13 displayed delayed learning, improving his performance from 83.33% in the first block of AB/BC Mixed Training, to 100% in the second block. Finally, Participant 15 responded 66.67% correct on the first block of training but a perfect 100% in the second block. However, the overall average was 83.34% and therefore that participant did not reach the overall mastery criterion in the AB/BC Mixed Training stage.

Table 9:

Breakdown of individual performance during ABT, ABE, BCT, BCE and AB/BC stages in Experiment 2.1

Ptp. No	ABT				ABE				BCT				BCE				AB/BC		
	1-18	19-36	37-54	AVRG	55-72	73-90	91-108	AVRG	109-126	127-144	145-162	AVRG	163-180	181-198	199-216	AVRG	217-233	234-252	AVRG
1	27.78	50.00	100.00	59.26	100.00	100.00	100.00	100.00	66.67	100.00	100.00	88.89	100.00	100.00	100.00	100.00	88.89	94.44	91.67
2	55.54	100.00	100.00	85.18	100.00	94.44	88.89	94.44	33.33	77.78	100.00	70.37	94.44	100.00	94.44	96.29	88.89	83.33	86.11
3	72.22	83.33	94.44	83.33	88.89	94.44	100.00	94.44	88.89	94.44	94.44	92.59	100.00	94.44	100.00	98.15	88.89	100.00	94.45
4	38.89	83.33	94.44	72.22	100.00	100.00	100.00	100.00	50.00	94.44	100.00	81.48	100.00	100.00	100.00	100.00	100.00	94.44	97.22
5	61.11	94.44	100.00	85.18	100.00	88.89	88.89	92.59	66.67	94.44	94.44	85.18	100.00	100.00	94.44	98.15	100.00	100.00	100.00
6	22.22	50.00	55.56	42.59	33.33	33.33	33.33	33.33	72.22	88.89	100.00	87.04	100.00	100.00	100.00	100.00	88.89	100.00	94.45
7	83.33	94.44	94.44	90.74	100.00	100.00	94.44	98.15	66.67	100.00	100.00	88.89	100.00	88.89	94.44	94.44	100.00	100.00	100.00
8	50.00	61.11	83.33	64.81	66.67	66.67	94.44	75.93	55.56	94.44	100.00	83.33	100.00	100.00	100.00	100.00	94.44	100.00	97.22
9	22.22	22.22	27.78	24.07	27.78	27.78	16.67	24.08	44.44	50.00	88.89	61.11	88.89	77.78	88.89	85.19	94.44	88.89	91.67
10	27.78	44.44	44.44	38.89	50.00	50.00	50.00	50.00	55.56	77.78	77.78	70.37	100.00	83.33	88.89	90.74	88.89	94.44	91.67
11	77.78	100.00	100.00	92.59	100.00	94.44	100.00	98.15	94.44	100.00	100.00	98.15	100.00	100.00	100.00	100.00	83.33	100.00	91.67
12	83.33	100.00	94.44	92.59	100.00	94.44	100.00	98.15	83.33	94.44	94.44	90.74	100.00	100.00	94.44	98.15	94.44	100.00	97.22
13	61.11	94.44	88.89	81.48	100.00	100.00	94.44	98.15	77.78	100.00	100.00	92.59	100.00	88.89	94.44	94.44	66.67	100.00	83.34
14	16.67	33.33	88.89	46.30	50.00	83.33	100.00	77.78	66.67	100.00	88.89	85.19	100.00	94.44	94.44	96.29	88.89	100.00	94.45
15	50.00	83.33	94.44	75.92	100.00	88.89	100.00	96.30	88.89	88.89	94.44	90.74	94.44	100.00	94.44	96.29	94.44	100.00	97.22
16	72.22	100.00	100.00	90.74	100.00	100.00	100.00	100.00	88.89	100.00	100.00	96.30	100.00	94.44	100.00	98.15	100.00	100.00	100.00
17	55.56	94.44	88.89	79.63	100.00	100.00	94.44	98.15	61.11	94.44	100.00	85.18	100.00	88.89	100.00	96.30	88.89	88.89	88.89
Average	51.63	75.81	85.29	70.91	83.33	83.33	85.62	84.10	68.30	91.18	96.08	85.18	98.69	94.77	96.40	96.62	91.18	96.73	93.95

Note: Performance above 88% mastery criterion in boldface

Only one participant (Participant 14) showed delayed emergence during equivalence testing (see Table 10 below). In the first trial block, this participant scored 77.78% correct, in the second block 44.44% and in the third and final block 94.44% correct. However, this was not enough to elevate his average above the mastery criterion and he was therefore not included in the Pass group. Participants 1, 3, 12 and 13 all showed an improvement in performance from the first to second equivalence test block. Additionally, if a two block delayed emergence criterion would be applied on their test data, they would all have been considered to have shown delayed emergence. However, all of those participants' performance either dropped slightly in the third block or stayed constant, although none of them fell below the mastery criterion. Participant 1 scored 88.89, 94.94 and 94.94 percent correct, Participant 3 and Participant 12 scored 94.44 in the first block and 100% in the last two. Finally, Participant 13 scored 88.89 in the first block, 100 %, and dropped slightly to 94.44% in the third and final testing block. Participants 7 and 10 both reached the mastery criterion during the equivalence test stage. However, their performance during the three equivalence test blocks steadily deteriorated, going from 94.44% correct in the first block to 83.33% in the third block of testing. Participants 4, 11 and 16 all showed stable performance during all three blocks of equivalence testing.

Table 10:

Breakdown of individual performance during CA, AC and BA/CB stages in Experiment 2.1

Ptp. No	CA				AC				BACB						
	253-270	271-288	289-306	AVRG	307-324	325-342	343-360	AVRG	361-378	379-396	397-414	415-432	433-450	451-468	AVRG
1	88.89	94.44	94.44	92.59	100.00	100.00	94.44	98.15	100.00	94.44	77.78	94.44	88.89	94.44	91.67
2	33.33	11.11	11.11	18.52	16.67	0.00	0.00	5.56	77.78	88.89	88.89	94.44	100.00	100.00	91.67
3	94.44	100.00	100.00	98.15	100.00	100.00	100.00	100.00	100.00	94.44	88.89	88.89	100.00	94.44	94.44
4	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	94.44	100.00	100.00	100.00	99.07
5	33.33	38.89	33.33	35.18	38.89	33.33	38.89	37.04	94.44	94.44	100.00	94.44	94.44	100.00	96.29
6	38.89	33.33	38.89	37.04	33.33	38.89	33.33	35.18	72.22	83.33	72.22	83.33	83.33	83.33	79.63
7	94.44	88.89	83.33	88.89	38.89	33.33	27.78	33.33	27.78	44.44	22.22	50.00	38.89	61.11	40.74
8	33.33	38.89	38.89	37.04	33.33	33.33	33.33	33.33	94.44	77.78	77.78	66.67	72.22	61.11	75.00
9	33.33	27.78	27.78	29.63	38.78	38.78	33.33	36.96	66.67	55.56	61.11	66.67	38.89	66.67	59.26
10	94.44	94.44	83.33	90.74	88.89	77.78	94.44	87.04	94.44	83.33	83.33	88.89	94.44	88.89	88.89
11	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	88.89	100.00	88.89	88.89	100.00	94.44	93.52
12	94.44	100.00	100.00	98.15	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
13	88.89	100.00	94.44	94.44	94.44	100.00	100.00	98.15	100.00	83.33	94.44	100.00	100.00	94.44	95.37
14	77.78	44.44	94.44	72.22	83.33	88.89	100.00	90.74	94.44	100.00	94.44	94.44	83.33	77.78	90.74
15	100.00	88.89	94.44	94.44	94.44	83.33	94.44	90.74	100.00	94.44	94.44	94.44	94.44	88.89	94.44
16	100.00	94.44	100.00	98.15	100.00	100.00	100.00	100.00	100.00	100.00	100.00	94.44	100.00	100.00	99.07
17	38.89	44.44	33.33	38.89	27.78	38.89	33.33	33.33	33.33	61.11	55.56	44.44	50.00	50.00	49.07
Average	73.20	70.59	72.22	72.00	69.93	68.62	69.61	69.38	84.97	85.62	82.03	84.97	84.64	85.62	84.64

Note: Performance above the 88% mastery criterion in boldface. Trial numbers continue from Table 11.

EEG results. EEG data was analyzed for all 10 participants that displayed equivalence in the 6th stage of the Experiment. Chosen for analysis were Baseline, A-B Training, B-C Extinction and C-A Equivalence. In previous experiments, the AB/BC Training was chosen instead of A-B or B-C Training or Extinction. The reason for that was the variability in the behavioural data during those stages in previous experiments. The experimental protocol employed here allowed for greater control over behavioural variability and thus the initial effects of training (A-B Training) could be compared to both well trained performance (B-C Extinction) as well as a novel problem (C-A Equivalence). Additionally, any possible effects of feedback stimuli were excluded by analyzing an extinction stage. Statistical analysis consisted of first a 4x3x3 (Stage x Front-Central-Posterior regions x Left-Mid-Right regions) repeated measures ANOVA on each of the frequency bands. If a significant effect was detected in the 4x3x3 ANOVA a one-way repeated measure ANOVA was then performed on each of the nine regions. Holm-Bonferroni corrections were applied to the p values (critical value .0056) of the one-way repeated measures ANOVAs. Additionally, all the regions were collapsed into one for a grand average measure by adding the region values together and dividing that number by nine. Holm-Bonferroni corrections were used on all pairwise comparisons (critical value .0125) within each individual region (differences between the experimental stages).

Delta (0.5-3.5 Hz). A 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed to assess any effects of Stage on delta power on the Coronal and Sagittal planes. Stage had a significant large effect on overall delta EEG power, ($F_{3, 27} = 40.727, p < .001, \eta_p^2 = .819$), as can be seen in Figure 19. A small Sagittal effect was found, ($F_{2, 18} = 4.693, p = .023, \eta_p^2 = .343$), as the Midline regions (Mid-Frontal, Mid-Central and Mid-Posterior) displayed significantly higher delta activity than the Right regions ($p = .028$) throughout the experiment. No significant differences were found between Midline and Left

regions ($p = .221$) or Left and Right regions ($p = .064$). No interaction effect was found between Stage and Coronal activity, ($F_{6, 54} = 1.551, p = .179, \eta_p^2 = .147$), or Stage and Sagittal activity, $F_{6,54} = 1.008, p = .430, \eta_p^2 = .101$. However, a small three way Stage x Coronal x Sagittal interaction was found, ($F_{12, 108} = 1.858, p = .048, \eta_p^2 = .171$).

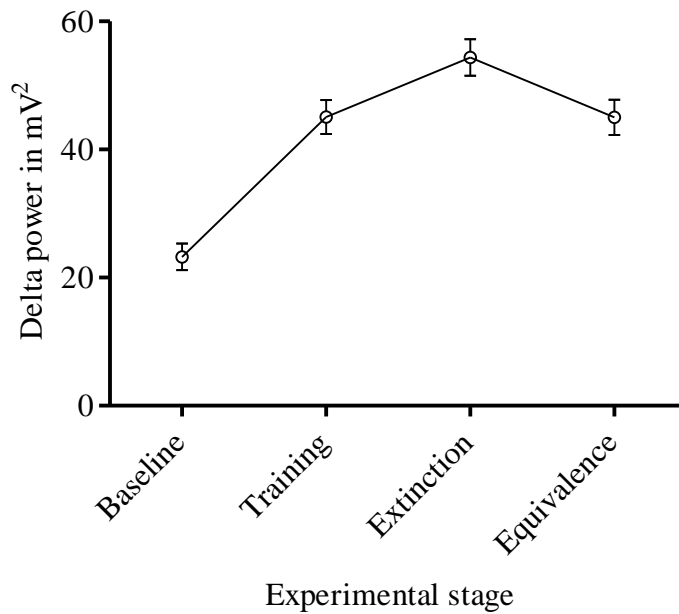


Figure 19. Grand average and standard error of EEG delta power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 2.1.

The lowest delta EEG power was registered during Baseline, lower than any of the three task conditions. Extinction registered significantly higher delta EEG power than both Training ($p < .001$) and Equivalence ($p < .001$). No significant differences were found between Training and Equivalence in overall delta power. As in previous experiments, a repeated measures one-way ANOVA was performed on each of the nine brain regions to further assess any Stage related changes in EEG power. The F and p values and degrees of freedom for each of the individual region ANOVAs are summarized in Table 11.

Table 11.

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 2.1 at each of the brain regions for the delta frequency

Delta (0.5-3.5 Hz)				
Brain region	F	p	η_p^2	df
LF	15.771	<.001*	.637	3,27
MF	4.076	.016*	.312	3,27
RF	8.205	<.001*	.477	3,27
LC	15.722	<.001*	.636	3,27
MC	13.414	<.001*	.598	3,27
RC	20.973	<.001*	.700	3,27
LP	24.920	<.001*	.735	3,27
MP	41.541	<.001*	.822	3,27
RP	33.777	<.001*	.790	3,27

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

*Significant effect following Holm-Bonferroni corrections

All regions showed a significant effect of Stage on EEG delta power as can be seen in Table 13. Delta power was highest during Extinction in all regions. In the Left-Frontal region Baseline delta power was significantly lower than all other stages of the Experiment (all $p < .005$). In the Mid-Frontal region, no stage differences were found in the pairwise comparisons. In the Right-Frontal region, delta power during Baseline was significantly lower than during Training ($p = .007$) and Extinction ($p = .004$). Delta power during Extinction was also significantly higher than during Equivalence ($p = .012$).

In the Left-Central region, Baseline delta power was significantly lower than all other experimental stages (all $p < .001$). In the Mid-Central region, Baseline delta power was significantly lower than Training ($p = .006$), Extinction ($p < .006$) and Equivalence ($p = .017$). In the Right-Central region, Baseline delta power was significantly lower than all other

stages of the Experiment (all $p < .001$). Additionally, delta power during Extinction was significantly higher than during Equivalence ($p = .013$).

In the Left-Posterior region, Baseline delta power was significantly lower than all other stages (all $p \leq .001$). Delta power during Extinction was also significantly higher than Training ($p = .002$). In the Mid-Posterior region, Baseline delta power was significantly lower than during all other stages (all $p < .001$). Delta power during Extinction was also significantly higher than Equivalence ($p = .005$). Finally, in the Right-Posterior region, Baseline delta power was significantly lower than during all other stages of the experiment (all $p < .001$). The average and standard error for each region during the four stages chosen for analysis can be seen in Figure 20.

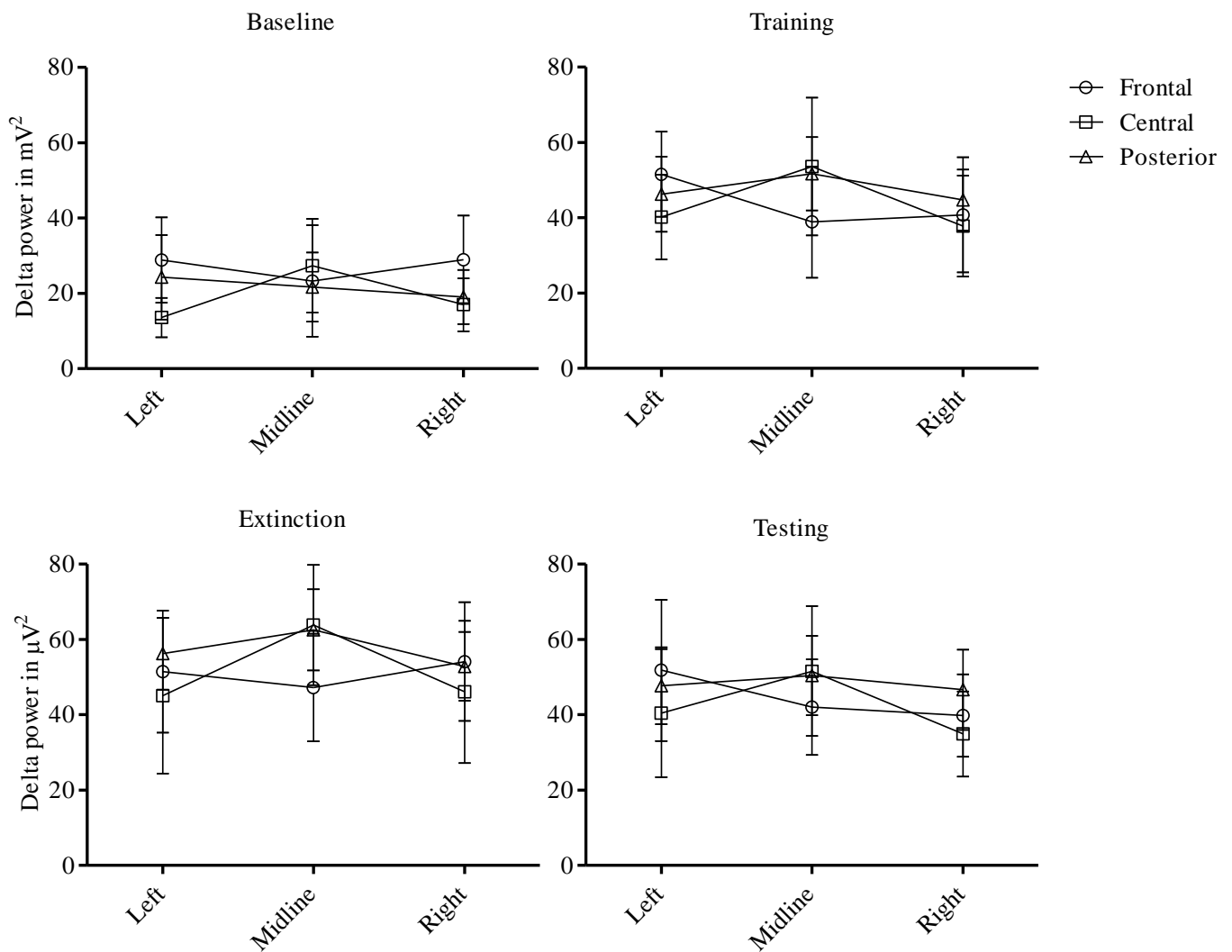


Figure 20. Average delta power values in μV^2 and standard error in all 9 regions used for analysis during Baseline, Training, Extinction and Testing in Experiment 2.1.

Theta (3.5-7.5 Hz). A 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed to assess any effects of Stage on theta power on the Coronal and Sagittal planes. Stage had a significant medium sized effect on overall delta EEG power, ($F_{3,27} = 14.587, p < .001, \eta_p^2 = .618$). As can be seen in Figure 21 this effect could be attributed mostly to Baseline being significantly lower than Training ($p < .001$), Extinction ($p = .008$) and Equivalence ($p = .001$). No significant differences in overall theta power were found between the three task stages.

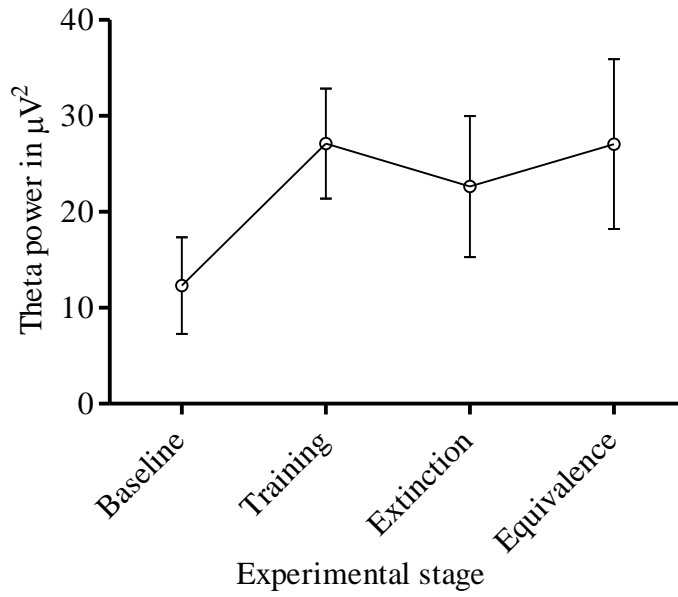


Figure 21. Grand average and standard error of EEG theta power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 2.1.

A small Sagittal effect was found, ($F_{2,18} = 7.844, p = .004, \eta_p^2 = .466$), as the Midline regions (Mid-Frontal, Mid-Central and Mid-Posterior) displayed significantly higher theta activity than the Left regions ($p = .012$) throughout the experiment.

A repeated measure one-way ANOVA was performed on each of the nine brain regions to further explore the effects of Stage on theta EEG power. The results can be seen in Table 12 below.

Table 12.

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 2.1 at each of the brain regions for the theta frequency.

Theta (3.5-7.5 Hz)				
Brain region	F	p	η_p^2	df
LF	3.901	.019*	.302	3, 27
MF	11.077	<.001*	.552	3, 27
RF	7.218	.001*	.445	3, 27
LC	7.330	.001*	.468	3, 27
MC	2.647	.069	.227	3, 27
RC	8.746	<.001*	.493	3, 27
LP	21.624	<.001*	.706	3, 27
MP	18.778	<.001*	.676	3, 27
RP	12.719	<.001*	.586	3, 27

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

*Significant effect following Holm-Bonferroni corrections

As can be seen in Table 12, Stage had a significant effect on all of the nine brain regions except Mid-Central. No significant differences between stages were found in the Left-Frontal region after Holm-Bonferroni corrections. Baseline theta power was significantly lower than during all other stages in the Mid-Frontal region (all $p = /<.007$). No other significant differences were found in the Mid-Frontal region. In the Right-Frontal region, Baseline theta power was significantly lower than both Training ($p = .012$) and Equivalence ($p = .003$). Additionally, theta power during Extinction was significantly lower than during Equivalence ($p = .007$).

In the Left-Central region, Baseline theta power was significantly lower than all other stages of the experiment ($p = .001, .025$ and $.005$). No other significant differences were found in the Left-Central region. No differences between stages were found in the Mid-

Central region. In the Right-Central region, Baseline theta power was significantly lower than during all other stages of the experiment (all $p < .005$).

Baseline theta power in the Left-Posterior region was significantly lower than during all other stages of the experiment (all $p < .001$). Additionally, theta power during Extinction was significantly lower than during Training ($p = .002$). In the Mid-Posterior region, Baseline theta power was significantly lower than during all other stages of the experiment (all $p \leq .006$). Additionally, theta power during Extinction was significantly lower than during Equivalence ($p = .01$). Right-Posterior region, Baseline theta power was significantly lower than during all other stages of the experiment (all $p \leq .006$). The average theta power and standard error of all nine regions during all four stages of the Experiment can be seen in Figure 22.

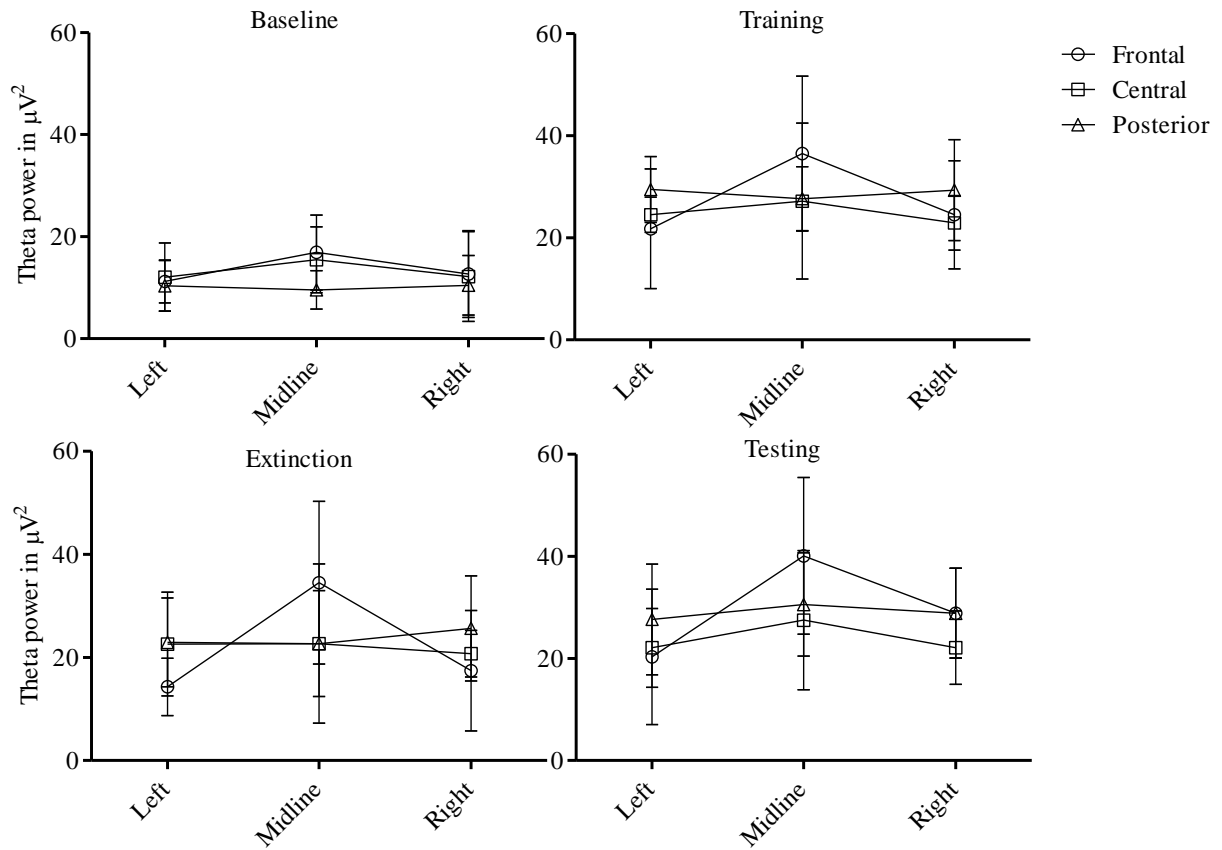


Figure 22. Average theta power values and standard error in μV^2 in all 9 regions used for analysis during Baseline, Training, Extinction and Testing.

Alpha (7.5-12 Hz). A 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed to assess any effects of Stage on alpha power on the Coronal and Sagittal planes. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2 = 24.947$, $p < .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = .418$). The results show that Stage had a medium sized significant effect on alpha power, ($F_{1.253, 11.276} = 27.034$, $p < .001$, $\eta_p^2 = .750$). Baseline alpha power was significantly higher than Training ($p = .001$), Extinction ($p < .001$) and Equivalence ($p = .001$). Alpha power during Extinction was also significantly lower than both Training ($p < .001$) and Equivalence ($p = .019$). The overall average alpha power during Baseline, Training, Extinction and Equivalence can be seen in Figure 23.

A significant Sagittal effect was found, ($F_{2, 18} = 9.475, p = .002, \eta_p^2 = .513$), as on average throughout the Experiment midline alpha power was higher than activity in both left ($p = .014$) and right ($p = .003$) regions.

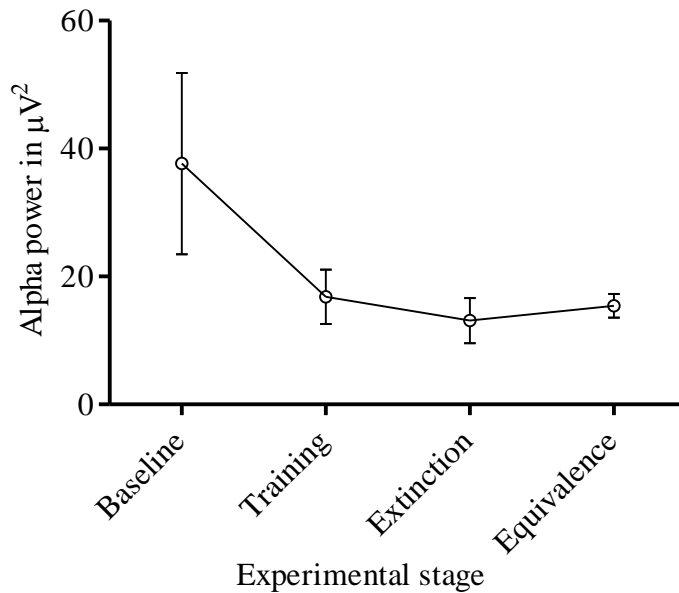


Figure 23. Grand average and standard error of EEG alpha power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 2.1.

A repeated measure one-way ANOVA was performed on each of the nine brain regions in an attempt to isolate the location of the effect of Stage on each region. The results can be seen in Table 13 below.

Table 13.

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 2.1 at each of the brain regions for the alpha frequency.

Alpha (7.5- 12 Hz)				
Brain region	F	p	η_p^2	df
LF	13.492	.002*	.600	1.4, 12.4 ⁺
MF	9.154	.008*	.504	1.3, 11.4 ⁺
RF	10.217	.005*	.532	1.4, 12.3 ⁺
LC	20.608	<.001*	.696	1.5, 13.5 ⁺
MC	17.206	<.001*	.657	3, 27
RC	21.483	<.001*	.705	1.5, 13.0 ⁺
LP	15.398	.002*	.631	1.3, 11.3 ⁺
MP	28.231	<.001*	.758	1.3, 11.8 ⁺
RP	21.769	<.001*	.707	1.5, 13.4 ⁺

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

* Significant effect following Holm-Bonferroni corrections

⁺ Degrees of freedom corrected with Greenhouse-Geisser

Stage had a significant effect on all brain regions as Baseline alpha power was significantly higher than any of the task conditions at all regions. In the Left-Frontal region, Baseline alpha power was significantly higher than all other stages of the Experiment (all $p \leq .014$). In the Mid-Frontal region, Baseline alpha power was significantly higher than all other stages of the Experiment (Training, $p = .046$, Extinction, $p = .005$, Equivalence, $p = .011$). In the Right-Frontal region, Baseline alpha power was significantly higher than during any of the other stages (Training, $p = .016$, Extinction, $p = .007$, Equivalence, $p = .007$).

The only significant differences in the Left-Central region were between Baseline and all other stages of the Experiment (Training, $p = .001$, Extinction, $p < .001$, Equivalence, $p < .001$). In the Mid-Central region, Baseline alpha power was significantly higher than during

all other stages of the Experiment (Training, $p = .005$, Extinction, $p < .001$, Equivalence, $p = .002$). In the Right-Central region, Baseline alpha power was significantly higher than during all other stages of the Experiment (Training, $p < .001$, Extinction, $p = .001$, Equivalence, $p = .001$).

In the Left-Posterior region, Baseline alpha power was significantly higher than during all other stages of the Experiment (Training, $p = .003$, Extinction, $p = .003$, Equivalence, $p = .002$). In the Mid-Posterior region, Baseline alpha power was significantly higher than during all other stages of the Experiment (Training, $p = .001$, Extinction, $p < .001$, Equivalence, $p = .001$). In the Right-Posterior region, Baseline alpha power was significantly higher than during all other stages of the Experiment (Training, $p = .001$, Extinction, $p < .001$, Equivalence, $p = .001$). Average alpha power and standard error at each region during all four stages can be seen in Figure 24 below.

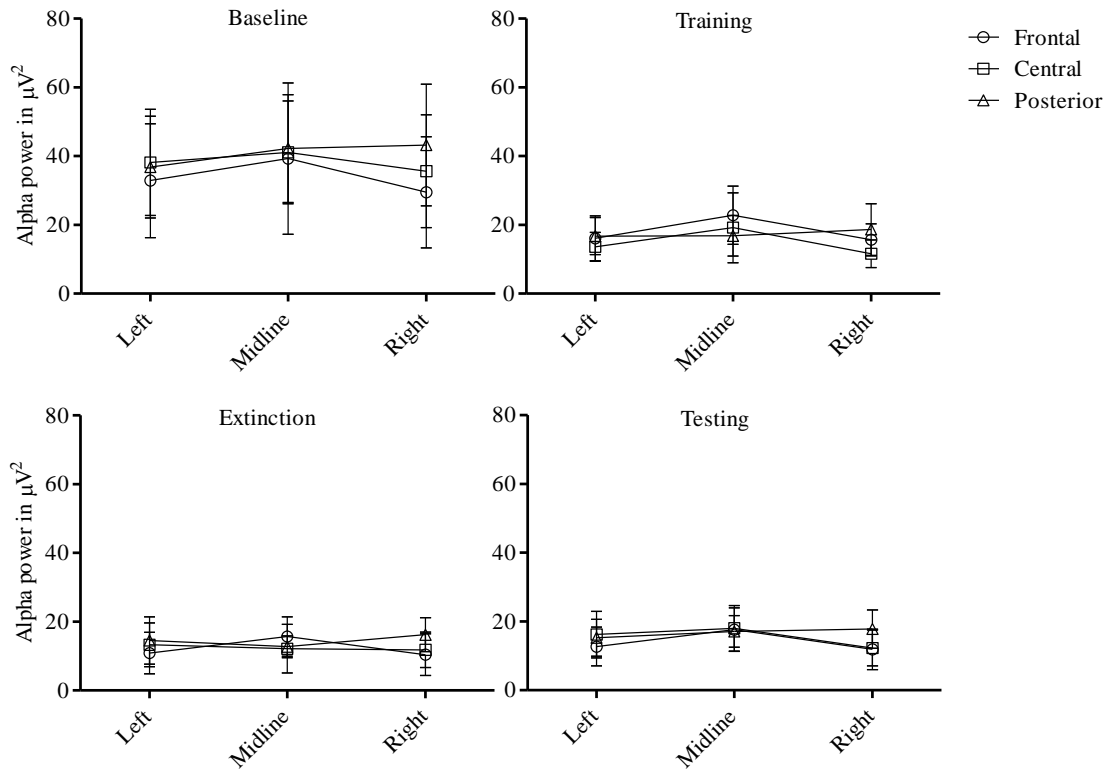


Figure 24. Average alpha power values and standard error in μV^2 in all 9 regions used for analysis during Baseline, Training, Extinction and Testing in Experiment 2.1.

Beta (12-30 Hz). A 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed to assess any effects of Stage on beta power on the Coronal and Sagittal planes. Significant effects were found for Stage, ($F_{3,27} = 26.356, p < .001, \eta_p^2 = .745$), Coronal, ($F_{2,18} = 5.898, p = .011, \eta_p^2 = .396$), and Sagittal, ($F_{2,18} = 11.407, p = .001, \eta_p^2 = .559$), activity. Overall, beta power was greatest during Baseline, significantly higher than during any of the three Task stages (see Figure 26). No significant differences were found in the overall beta power between the three Task stages. The Coronal effect was mostly due to overall Frontal beta power being greater than both Central ($p = .021$) and Posterior ($p = .009$) power. The Sagittal effect was due to overall Midline beta power being significantly lower than both Left ($p = .006$) and Right ($p = .001$) power. No Stage x Coronal or Stage x Sagittal interaction effects were found although Stage x Coronal did approach significance ($p = .051$).

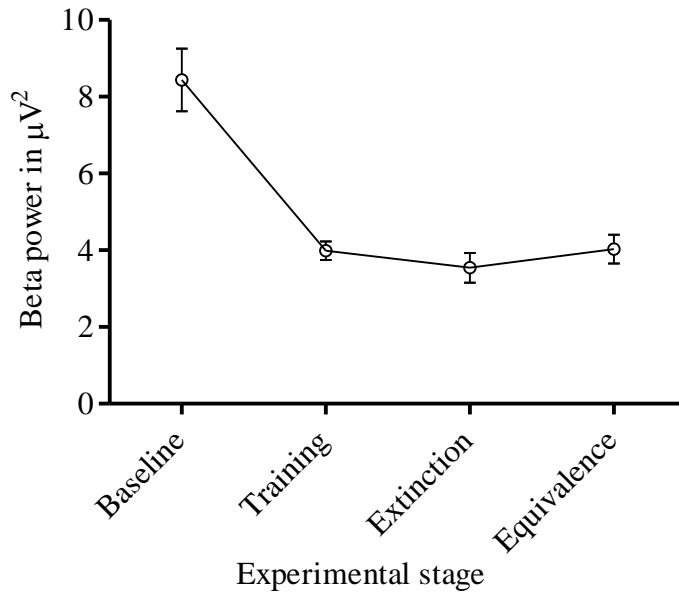


Figure 25. Grand average in μV^2 and standard error of EEG beta power during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 2.1.

Baseline beta power was significantly higher than Training, Extinction and Equivalence ($p < .001$ in all three respectively). No differences were found between the three Task stages in overall beta power. A repeated measure one-way ANOVA was performed on each of the nine brain regions in an attempt to isolate any localized effects. The results can be seen in Table 14 below.

Table 14.

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 2.1 at each of the brain regions for the beta frequency.

Beta (12 – 30 Hz)				
Brain region	F	p	η_p^2	df
LF	13.255	<.001*	.596	3, 27
MF	7.906	.001*	.468	3, 27
RF	12.473	<.001*	.581	3, 27
LC	10.615	<.001*	.541	3, 27
MC	19.272	.001*	.682	1.2, 10.7 ⁺
RC	7.002	.001*	.438	3, 27
LP	13.984	<.001*	.608	3, 27
MP	37.437	<.001*	.806	3, 27
RP	15.142	<.001*	.627	1.7, 15.1 ⁺

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

* Significant effect

⁺ Degrees of freedom corrected with Greenhouse-Geisser

The average and standard error for each region during the four stages chosen for analysis can be seen in Figure 26 below. Stage had a significant effect on all brain regions as Baseline beta power was significantly higher than any of the task conditions at all regions (all $p \leq .05$).

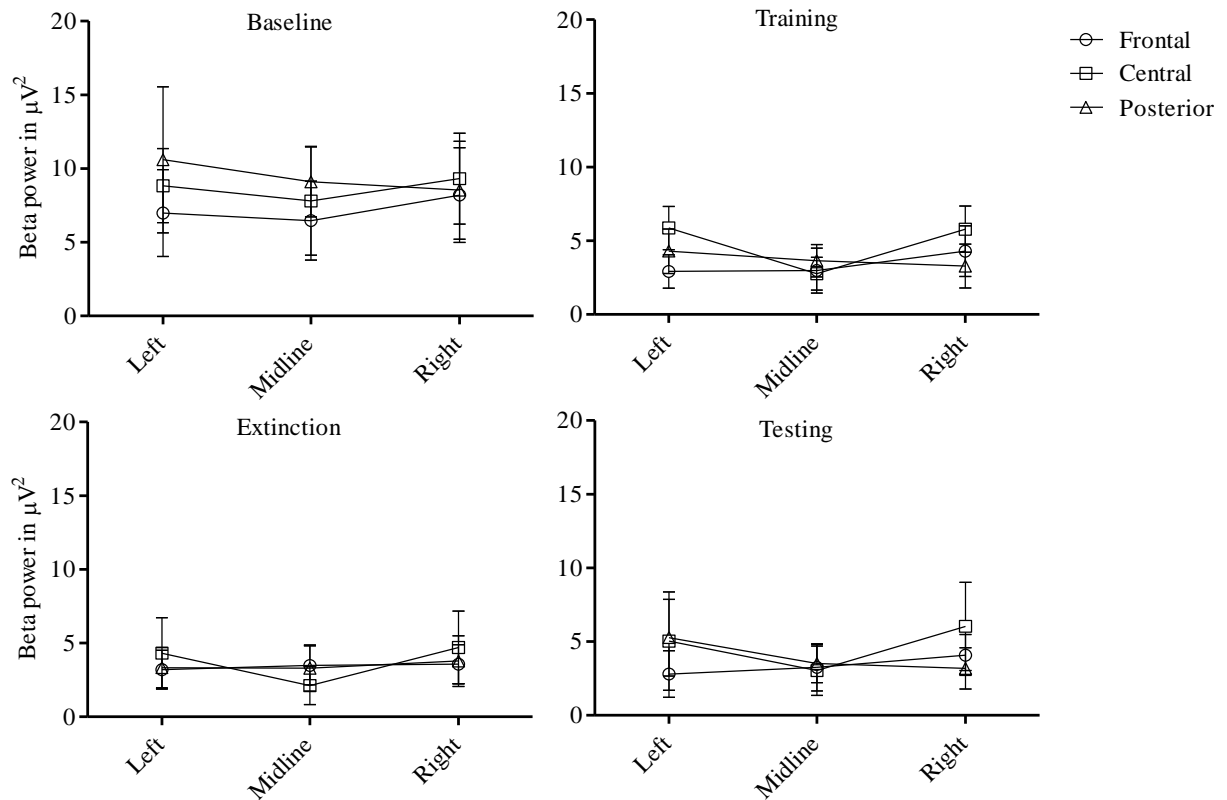


Figure 26. Average beta power values in μV^2 and standard error in all 9 regions used for analysis during Baseline, Training, Extinction and Testing in Experiment 2.1.

Gamma (30-40 Hz). A 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed to assess the effects of Stage on the Coronal and Sagittal planes. For Stage, Mauchly's test indicated that the assumption of sphericity had been violated (chi-square = 13.638, $p = .019$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (epsilon = .509). The results show that Stage had a significant effect on gamma power, ($F_{1.527, 13.742} = 27.034$, $p = .012$, $\eta_p^2 = .432$). As can be seen in Figure 27 Baseline gamma power was significantly higher than Extinction ($p = .015$).

A Coronal effect was also found, ($F_{2, 18} = 5.708$, $p = .012$, $\eta_p^2 = .388$), as overall Posterior gamma power was significantly lower than both Frontal ($p < .001$) and Central ($p < .001$). A Sagittal effect was found, ($F_{2, 18} = 22.318$, $p < .001$, $\eta_p^2 = .713$), where Midline overall gamma power was significantly lower than both Left ($p < .001$) and Right ($p < .001$)

gamma power. Additionally, gamma power on the Right side was significantly lower than on the Left side ($p = .025$). For Stage x Coronal, Mauchly's test indicated that the assumption of sphericity had been violated (chi-square = 56.078, $p < .001$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (epsilon = .652). The results show a small but significant Stage x Coronal interaction, ($F_{2.763, 24.869} = 5.748$, $p = .007$, $\eta_p^2 = .272$).

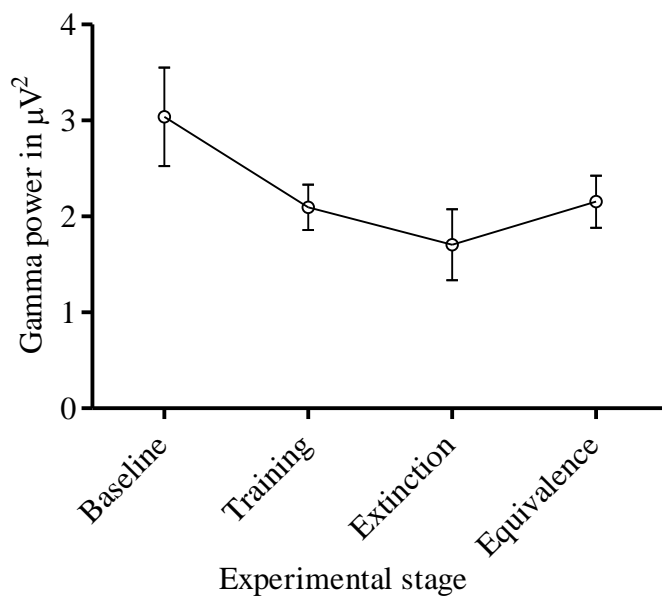


Figure 27. Grand average and standard error of EEG gamma power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 2.1.

Baseline gamma power was significantly higher than Extinction ($p = .015$). No significant differences were found in gamma power between the Task stages. A repeated measure one-way ANOVA was performed on each of the nine brain regions in an attempt to isolate any localized effects of Stage in gamma power. The results can be seen in Table 15 below.

Table 15.

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 2.1 at each of the brain regions for the gamma frequency

Brain region	Gamma (30-40 Hz)			
	F	p	η_p^2	df
LF	2.649	.069	.227	3, 27
MF	1.353	.278	.131	1.5, 13.1 ⁺
RF	2.197	.112	.196	3, 27
LC	2.252	.105	.200	3, 27
MC	12.333	.003*	.578	1.3, 11.5 ⁺
RC	2.225	.108	.198	3, 27
LP	9.197	.008*	.505	1.3, 11.3 ⁺
MP	16.526	<.001*	.647	1.6, 14.5 ⁺
RP	7.501	.011*	.455	1.4, 13.0 ⁺

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

* Significant effect following Holm-Bonferroni corrections

⁺ Degrees of freedom corrected with Greenhouse-Geisser

Stage had a significant effect on four regions - Mid-Central and all three posterior regions. In the Mid-Central region, Baseline gamma was significantly higher than during all other stages of the Experiment (Training, $p = .006$, Extinction, $p = .003$, Equivalence, $p = .014$). Gamma power during Extinction was also significantly lower than during Equivalence ($p = .001$).

In the Mid-Posterior region, Baseline gamma power was significantly higher than all other stages of the Experiment (Training, $p = .003$, Extinction, $p < .001$, Equivalence, $p < .001$). No other pairwise differences were preserved following Holm-Bonferroni corrections. Average gamma power and standard error in all 9 regions can be seen in Figure 28 below.

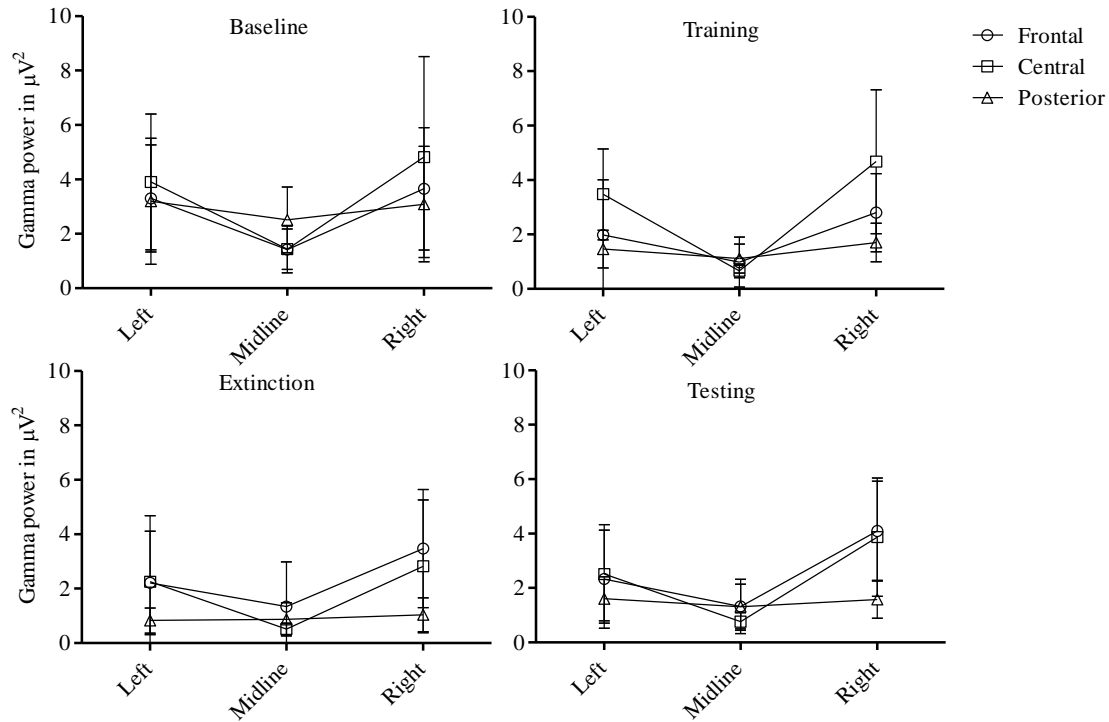


Figure 28. Average gamma power in μV^2 values and standard error in all 9 regions used for analysis during Baseline, Training, Extinction and Testing in Experiment 2.1.

Discussion. As expected, the results obtained yielded two almost equal groups of Pass (10 participants) and Fail (7 participants), and addressed most of the issues raised with the previous protocol. First, the AB and BC training stages and the Equivalence and Transitivity testing stages, now included 54 trials, and the AB/BC mixed training included 36 trials. This meant that more epochs of clean EEG data were available for analysis, allowing more robust interpretation of the EEG data. Second, the difference in the experimental protocol also meant that participants would be split into fairly easily identifiable groups of Pass and Fail as they were only exposed to the protocol once and the number of trials was kept consistent between participants. The third issue raised with the previous protocol was the difference between Pass and Fail groups. Although comparing the behavioural results was possible with the current protocol, the low number of participants in each group would make the statistical

assumptions very weak. Results from Experiment 2.1 will therefore be combined with those from Experiment 3.1 to further explore this difference. The fourth issue with the previous protocol was the number of stimuli presented and the location of the stimuli on screen. This was rectified by reducing the number of equivalence classes to 3, and by displaying the sample and the comparison in the centre of the screen, thereby minimizing eye movement. Lastly, the length of the experimental exposure never exceeded 30 minutes for each participant; as opposed to up to 3 hours in the previous protocol, thereby minimizing greatly any possible fatigue effect, both on behavioural performance and EEG activity.

Differences between the groups were visible from the AB training stage, as the Pass group responded with 77.78% accuracy, while the Fail groups' average was 58.02 percent. However, variation in performance was great in both groups, making it hard to predict individual performance on the equivalence test from the performance during the AB training stage. The same pattern was observed in the AB Extinction stage, when the Pass groups' performance was near optimal level, with all but one of the group responding with accuracy of 94% or higher. The Fail groups' performance also improved, but the group had more variability than the Pass group.

When compared to the results of training in Experiment 1.1, the results here compare favourably. In both experiments, almost all participants did master the AB and BC training tasks before advancing to the testing stages. A difference between the Pass and Fail groups was visible during AB training in the protocol used in Experiment 2.1 which was not evident in the previous experiment. In Experiment 1.1, 14 of the 18 participants showed fairly rapid learning but in Experiment 2.1 a clear group difference was observed. During BC training, a similar trend was observed in both Experiment 1.1 and 2.1 as performance improved during BC training when compared to AB training. However, this improvement was more pronounced in Experiment 1.1, than in 2.1, as in the latter experiment a difference was

observed between the Pass and Fail groups that was not evident in Experiment 1.1. In the AB/BC Training the results are almost identical in the two experiments. In Experiment 1.1, 16 of the 17 participants exposed to that stage only needed the minimum amount of trials (72) to proceed. In Experiment 2.1, 15 of the 17 participants responded with 90% or higher accuracy in the AB/BC stage, and the remaining two scored 83.34% and 88.80% respectively.

During Equivalence testing in Experiment 2.1, only one participant (Participant 14) displayed a response pattern that could be labelled delayed emergence of equivalence, responding with 77.78% correct in the first block of testing, dropping down to 44.44% correct in the second block, and finally responding correctly at 94.44% in the last block. Other participants that showed an improvement in performance during the three Equivalence testing blocks always responded above the mastery criterion. Two participants' performance dropped during the equivalence testing. In the first testing block, Participant 7 responded correctly 94.44%, then dropped slightly to 88.89% and then dropped below the mastery criterion to 83.33% in the third block. Participant 10 responded correctly 94.44% in the first two training blocks before dropping to 83.33% in the third block. This response pattern was not reported by Holth & Arntzen (1998). The two participants did show a slight decrease in accuracy during the AB and BC Extinction stages as well. This decrease during equivalence testing might be due to lack of reinforcement during the testing and extinction stages. In fact, Participant 7 did show a decrease in accuracy during Transitivity, from 38.89% correct to 33.33% correct and finally to 27.78% correct. However, Participant 10 did not show this pattern of responding, scoring 88.89% correct on the first Transitivity block, and then dropping down to 77.78% before improving to 94.44% in the final block. Overall, this result is somewhat surprising as according to Holth & Arntzen (1998) delayed emergence are more likely to occur in participants that are only exposed once to the experimental protocol, instead

of those that are re-trained after failing the equivalence test. It is possible that the multiple training trials used in the current protocol served as a substitute for multiple exposures. The multiple trials served to solidify the connection between the 'A' and 'B' stimuli and 'B' and 'C' stimuli, for both participants that learned the connections quickly and those that took longer to learn.

To minimize any possible fatigue effects on the EEG, the Equivalence testing stage was the first test administered, as opposed to the last test in Experiment 1.1 and 1.2. AB/BC testing was also not included, another method used to shorten the experimental procedure. It is difficult to compare test results in any detail between the two experiments for a number of reasons. The first is the number of trials was much greater in Experiment 2.1 than in Experiment 1.1. Fewer equivalence classes were trained in Experiment 2.1 than in the previous experiment, and the training was set to a prefixed amount of trials, rather than the participants advancing only when they responded to a criterion. Overall, the protocol used in Experiment 1.1 seems to be better suited to train participants to display equivalence, and the protocol used in Experiment 2.1 was better suited to split the sample into two groups and to record more reliable EEG data.

Overall delta power was greatest during Extinction, significantly higher than both Training and Equivalence. In Experiment 2.1, delta power during Extinction was significantly higher than during Training at the Left-Posterior region and significantly higher than Equivalence at the Right-Frontal and Mid-Posterior regions. An increase in delta power during the course of an experiment, and not directly linked to the content of the task, has been reported in the literature (Brismar, 2007). This, however, could not be the case here, as delta power decreased during Equivalence. If the increase in delta during Extinction was purely due to the amount of time the participants were exposed to the experiment, a further decrease, or at least a plateau of delta power would have been expected. Brookings, Wilson & Swain

(1996) found that during a moderately difficult air traffic control task, delta power was higher than during difficult or easy versions of the task. If one would categorize the three task stages as Training being the easiest (due to feedback), Extinction moderately difficult (trained task but no feedback) and Equivalence the most difficult (novel categorization) the results here could be interpreted in the same vein. However, the behavioural results do not cohere with this task categorization, as participants performed better in the Extinction stage than during the Training stage. Harmony et al. (1996, 2001), have suggested that increases in delta activity can be caused by intense concentration during a task. This could also be the case in the current experiment, as participants did not receive feedback during the Extinction stage, which might have caused an increase in concentration when compared to Training. The drop in delta during Equivalence could then be response suppression (Schneider et al., 2008) or simply that other frequencies are dominant during complex responding.

As in Experiment 1.1, Stage had very little effects on theta power other than an increase in activity from Baseline to Task. However, at the Right-Frontal region, theta power during Extinction was significantly lower than during Equivalence, but not significantly different from Baseline levels. Increase in theta power has been reported in experiments on short term memory and tasks of verbal fluency, specifically in the frontal areas (Brickman et al., 2005). Training and Equivalence might be more reliant on verbal fluency or short term memory than Extinction. However, these interpretations must be taken with caution due to the large variability in theta power and a relatively small effect size. This lack of effect was contrary to expectations, and could be attributed to a variety of factors. Other analysis methods, such as coherence or wavelet analysis, might be able to detect changes in theta responses that the FFT cannot. As Sauseng & Klimesch (2008) have established, theta can occur in short bursts which would not be detected by the FFT analysis. Theta has mostly been linked with language or memory functions, and found to co-occur with remembering and

language processing. Theta activity at different locations has not only been linked with various different cognitive processes, but also memory strategies and mnemonics (private verbal behaviour). Gevins, Smith, McEvoy and Yu (1997) found that the type of processing used by participants in a categorization task altered the EEG activity observed. During spatial processing, alpha activity showed an increase, specifically in the posterior right region. This increase was contingent on the practice received by the participants before the administration of the task. In the current experiment, participants all received the same number of trials during training. However, this number of trials could have represented different levels of training for different participants. For example, one participant might only have needed 20 trials to learn the AB pairings, while another needed 44. The first participant then received 34 additional trials while the second only received 10 additional trials. This might have led to greater response suppression by the first participant, and distortion of the final data. It is unclear how this could be addressed with modifications of the current protocol. Having a set criterion, say similar to Experiment 1.1, but have a set maximum amount of trials might address this problem. However, a second problem arises, as participants might learn to pair members of one equivalence class (i.e. A1-B1) faster than members of another equivalence class (A2-B2). The EEG data would then be contaminated by this discrepancy in the rate of learning. The increased power in the Mid-Frontal region during all three stages was expected based on previous research (for example Sauseng & Klimesch, 2008). A possible reason for the lack of ANOVA stage effects in this area might be that the Mid-Frontal region is equally active throughout the experimental stages, which reflects the memory load requirements of the task.

Results for the alpha frequency were similar to those found for the delta and theta frequencies. Baseline alpha power was significantly higher than all task conditions. However, no difference was found in these regions between the three task stages.

Beta activity during Baseline was significantly higher than any of the task stages, but no differences were found between the task stages in overall beta activity. Although changes in beta activity have mostly been associated with motor activity and drowsiness in the same way as alpha activity (Finch, 1999), some researchers have implicated increases in beta with increases in task complexity. Brookings et al. (1996) reported that with increasingly complex tasks types, beta in Frontal and Central sites increased. According to Brookings et al., the changes in beta could be used as an indication of the type of processing needed for a task, rather than the difficulty of a task per se. The lack of clear effects here might be due to different strategies used by the participants, as hypothesised in the case of theta.

As was mentioned in the introduction, no clear functions have been assigned to the gamma frequency in the literature (Herrmann et al. 2004) as has been the case with for example theta. Therefore, all interpretation of results must be made with caution. The effects found in the gamma frequency were isolated to two regions, Mid-Central and Mid-Posterior.

At the Mid-Central region, gamma power during Extinction was higher than during Equivalence. During Extinction, a significant change was detected in gamma at Posterior and Central regions, when compared to the other stages. This Posterior decrease of gamma was expected, as Schneider et al. (2006) reported that repeated presentation of familiar stimuli lead to a decrease in total Posterior gamma band activity. This effect might therefore not be task related, but rather the effect of the repeated presentation of visual stimuli. The increases in the Right-Posterior gamma reported by Brzezicka et al. (2011) during a Transitive argument task were not found during the Equivalence testing. A few factors might have contributed to this. The effects reported by Brzezicka et al. were found during a Transitive test, but not an Equivalence test. Although both are derived relations, there are some differences in the exact definitions used in the two respective research traditions (behavioural and cognitive). The transitive task used by Brzezicka et al. did not involve any lengthy

training prior to testing. Participants were exposed to statements ($A > B$; $B > C$) and then directly tested on the truthfulness of the statement is ' $A > C$?' This difference could be one reason why an effect was not found in the current experiment. It is also possible that the different EEG analysis used in the current study and that of Brzezicka et al. might explain the different results. One difference was that the gamma frequency range was 35-60 Hz in the Brzezicka et al. Study but 30 to 40 Hz in the current study. This might make comparing the results from the two studies somewhat difficult. As Herrmann (2003, p. 176) showed, the power of the gamma frequency is fairly similar between 30 and 40 Hz but drops substantially in higher frequencies.

Experiment 2.2

Experiment 2.2 was designed to serve the same purpose as Experiment 1.2, which was to compare the effects of abstract stimuli on equivalence responding to the effects of iconic stimuli. The protocol used was the same as in Experiment 2.1, the A-B and B-C training stages had a pre-set limit of 54 trials each and participants were taught three equivalence classes instead of six in Study 1. The stimuli used were the first three stimulus classes used in Experiment 1.2. As has previously been mentioned iconic stimuli can facilitate equivalence responding due to learning histories associated with those stimuli (Arntzen, 2004). This learning history can decrease the number of trials needed for participants to successfully acquire the equivalence relations. It was expected that the increased number of exposures to each stimulus pair would facilitate the acquisition of abstract pairs. The increased number of trials during training in Experiment 2.2 as compared to Experiment 1.2 it was therefore expected that the yield in Experiment 2.2 would be similar to that seen in Experiment 1.2 but still below what was seen in Experiment 2.1 where iconic stimuli were used.

Method.

Participants. Fourteen healthy adult human (5 male) participants took part in the study. All participants were between 18 and 48 years of age, were right handed and had normal or corrected to normal eyesight; none reported taking psychotropic medication, or having sustained traumatic brain injury. All participants were first year students at the National University of Ireland Galway and participated as part of their course credit. The study was approved by the NUI Galway Research Ethics Committee.

Apparatus. Training and testing hardware and software were the same as in Experiment 2.1. The stimuli used were the first three equivalence classes (abstract stimuli) used in Experiment 1.2.

Stimuli. The stimuli were grouped together in classes of A1-B1-C1, A2-B2-C2 and A3-B3-C3. The alphanumeric labels refer to images used in the experiment but were not known to any of the participants. The stimuli used were the first three stimulus classes from Experiment 1.2.

General procedure. See General procedure in Experiment 2.1.

EEG data preparation and analysis. See description in Experiment 2.1.

Conditional discrimination training. Conditional discrimination training was identical to Experiment 2.1.

Results. Fourteen participants were recruited for the Experiment, and only one, P8, displayed equivalence. For that reason, the participants were not split into two groups as in previous experiments. Also, no EEG analysis was done at this stage. The behavioural results from all stages of the Experiment can be seen in Table 16 below.

Table 16

Percentage of correct responses during training and testing stages in Experiment 2.2

	AB Train	AB Ext	BC Train	BC Ext	ABBC Train	CA	AC	BA/CB
1	68.52	92.59	66.67	92.59	91.67	31.48	25.93	51.85
2	75.93	55.56	59.26	83.33	88.89	35.19	31.48	68.52
3	50.00	55.55	85.18	96.29	83.34	14.82	1.85	48.15
4	72.22	94.44	55.56	83.33	94.44	38.89	16.67	58.33
5	48.15	64.82	12.96	16.67	80.56	20.37	24.07	48.15
6	62.96	87.04	62.96	100.00	86.11	46.29	27.78	22.22
7	33.33	7.41	55.56	87.04	94.45	12.96	0.00	58.34
8	74.07	98.15	90.74	100.00	94.45	90.74	92.59	88.89
9	75.93	87.04	55.55	88.89	94.45	37.04	14.82	37.80
10	11.11	33.33	27.78	25.93	22.22	38.89	27.78	28.70
11	57.41	64.82	79.63	96.29	94.45	31.48	29.63	37.04
12	33.33	35.18	27.78	20.37	72.23	38.89	7.41	37.96
13	49.99	70.37	87.04	100.00	80.56	50.00	33.33	31.48
14	74.07	94.44	85.19	100.00	97.22	68.52	100.00	75.93

Note: Performance above the 88% mastery criterion in boldface

In the AB Training stage, participants averaged 56.22% correct, ranging from 11.11 to 75.93% correct. In the AB Extinction stage, the overall performance was 67.2% and the range of scores increased as the lowest score was 7.41% correct and the highest was 98.15% correct by Participant 8 who then displayed Equivalence. The highest score in the Fail group was 94.44% correct, displayed by Participants 4 and 14 respectively. When the experimental stages are broken down into 18 trial blocks (see Table 17 below), a slightly different response pattern emerges. No participant scored higher than 66.67% in the first block of trials. In the second block, only one participant reached the mastery criterion level but six participants reached the criterion in the last block of trials.

Two participants performed worse in AB Extinction than during AB Training. Participant 2's score fell from 75.93% to 55.56% and Participant 7's score fell from 33.33% to 7.41 percent. The trial block breakdown of ABE shows that four participants reached the mastery criterion in the first block of trials, and that all of those had reached the mastery criterion in the last block of ABT. Participant 6 initially reached the mastery criterion in the

first two blocks but then fell below the criterion in the third block. Participant 9 showed the opposite response pattern, initially scoring under the mastery criterion but then showing gradual learning, improving his performance in the second and third blocks of trials.

During the BC Training stage, the overall performance dropped to 60.85% from AB Extinction, but was higher than during the initial AB Training. Participant 5's performance stands out as it dropped substantially, to 12.96%, during the BC Training. Again, Participant 8 had the highest score and was the only one to reach the 88% criteria in the BC Training stage, although Participants 13 and 14 were close with 87.04% correct and 85.19% correct respectively. The trial breakdown shows that only one participant reached the mastery criterion in the first block of trials in BCT, and when compared to ABT the average performance is similar. Learning was slightly faster in the BCT stage than during ABT, as four participants reached the mastery criterion in the second block of BCT and the group average was almost 10% points higher than during ABT. However, during the third block this difference was not observed, as six participants reached the mastery criterion, the same number as in ABT.

As in the ABE stages, performance improved in the BC Extinction stage, compared to BCT, when the overall performance was 77.91% correct and eight participants scoring 88% or higher. Participants 10 and 12 both showed poorer performance during the BC Extinction than during the BC Training, although this drop was only minimal. Eight participants reached the mastery criterion in the first block in BCE. Additionally, Participant 1 responded 83.33% correct, which was significantly higher than other participants that failed to reach the criterion. In the second block, nine participants reached the mastery criterion but overall group performance did not improve significantly. Finally, in the third block, ten participants reached the mastery criterion, two of which did not reach the overall BCE stage mastery criterion (Participants 2 and 4).

In the AB/BC Training stage, all but one participant performed with over 70% accuracy, with an average of 83.93% correct responses and 8 participants reaching the 88% criterion. Nine participants reached the mastery criterion in both blocks of AB/BC. Participants 2, 5, and 6 showed an extinction response pattern, first responding 94.44% correct and in the second block responding 66.67% correct. Participant 1 was the only one to display learning during this stage, first responding 83.33% correct and 100% in the second block.

Table 17

Breakdown of individual performance during ABT, ABE, BCT, BCE and AB/BC in Experiment 2.2

Ptp. No	ABT				ABE				BCT				BCE				AB/BC		
	1-18	19-36	37-54	Avrg	55-72	73-90	91-108	Avrg	109-126	127-144	145-162	Avrg	163-180	181-198	199-216	Avrg	217-233	234-252	Avrg
1	44.44	72.22	88.89	68.52	88.89	94.44	94.44	92.59	33.33	66.67	100.00	66.67	83.33	94.44	100.00	92.59	83.33	100.00	91.67
2	55.56	83.33	88.89	75.93	61.11	55.56	50.00	55.56	22.22	72.22	83.33	59.26	94.44	66.67	88.89	83.33	94.44	83.33	88.89
3	27.78	50.00	72.22	50.00	72.22	50.00	44.44	55.55	66.67	94.44	94.44	85.18	100.00	94.44	94.44	96.29	66.67	100.00	83.34
4	44.44	77.78	94.44	72.22	83.33	100.00	100.00	94.44	16.67	83.33	66.67	55.56	72.22	77.78	100.00	83.33	94.44	94.44	94.44
5	38.89	38.89	66.67	48.15	61.11	66.67	66.67	64.82	11.11	16.67	11.11	12.96	33.33	5.56	11.11	16.67	94.44	66.67	80.56
6	33.33	61.11	94.44	62.96	94.44	88.89	77.78	87.04	38.89	72.22	77.78	62.96	100.00	100.00	100.00	100.00	88.89	83.33	86.11
7	50.00	27.78	22.22	33.33	5.56	16.67	0.00	7.41	50.00	50.00	66.67	55.56	88.89	94.44	77.78	87.04	100.00	88.89	94.45
8	44.44	77.78	100.00	74.07	100.00	94.44	100.00	98.15	88.89	83.33	100.00	90.74	100.00	100.00	100.00	100.00	88.89	100.00	94.45
9	66.67	83.33	77.78	75.93	77.78	88.89	94.44	87.04	33.33	61.11	72.22	55.55	66.67	100.00	100.00	88.89	88.89	100.00	94.45
10	11.11	11.11	11.11	11.11	44.44	22.22	33.33	33.33	22.22	38.89	22.22	27.78	16.67	27.78	33.33	25.93	11.11	33.33	22.22
11	44.44	55.56	72.22	57.41	55.56	72.22	66.67	64.82	44.44	94.44	100.00	79.63	94.44	94.44	100.00	96.29	88.89	100.00	94.45
12	38.89	33.33	27.78	33.33	33.33	27.78	44.44	35.18	27.78	33.33	22.22	27.78	27.78	27.78	5.56	20.37	77.78	66.67	72.23
13	27.75	61.11	61.11	49.99	61.11	66.67	83.33	70.37	77.78	94.44	88.89	87.04	100.00	100.00	100.00	100.00	66.67	94.44	80.56
14	38.89	88.89	94.44	74.07	88.89	94.44	100.00	94.44	66.67	88.89	100.00	85.19	100.00	100.00	100.00	100.00	94.44	100.00	97.22
Average	40.47	58.73	69.44	56.22	66.27	67.06	68.25	67.20	42.86	67.86	71.83	60.85	76.98	77.38	79.37	77.91	81.35	86.51	83.93

Note: Performance above the 88% mastery criterion in boldface

As mentioned above, only Participant 8 displayed Equivalence in the CA stage with 90.74% correct responses. The remaining participants scored between 12.96% correct to 68.52% correct with an average of 35.75% correct responses (see Table 18 below). Participant 14 did score noticeably higher than other Fail participants, finishing the CA stage with 68.52% correct responses. Additionally, during the AC stage, Participant 14 outscored P8, with 100% correct to 92.59% correct. This trend continued in the BA/CB stage, when Participant 14 again displayed substantially higher correct responses than other Fail participants.

Table 18

Breakdown of individual performance during CA, AC, and BA/CB in Experiment 2.2

Ptp. No	CA				AC				BACB						
	253-270	271-288	289-306	Avrg	307-324	325-342	343-360	Avrg	361-378	379-396	397-414	415-432	433-450	451-468	Avrg
1	33.33	27.78	33.33	31.48	33.33	27.78	16.67	25.93	61.11	50.00	55.56	55.56	50.00	38.89	51.85
2	50.00	27.78	27.78	35.19	22.22	38.89	33.33	31.48	55.56	72.22	77.78	72.22	77.78	55.56	68.52
3	38.89	5.56	0.00	14.82	0.00	5.56	0.00	1.85	44.44	44.44	38.89	61.11	27.78	72.22	48.15
4	33.33	44.44	38.89	38.89	38.89	11.11	0.00	16.67	72.22	61.11	55.56	44.44	66.67	50.00	58.33
5	44.44	11.11	5.56	20.37	27.78	22.22	22.22	24.07	61.11	33.33	44.44	55.56	38.89	55.56	48.15
6	72.22	33.33	33.33	46.29	22.22	33.33	27.78	27.78	33.33	16.67	27.78	16.67	27.78	11.11	22.22
7	0.00	11.11	27.78	12.96	0.00	0.00	0.00	0.00	38.89	61.11	72.22	55.56	55.56	66.67	58.34
8	83.33	88.89	100.00	90.74	88.89	100.00	88.89	92.59	66.67	94.44	88.89	94.44	100.00	88.89	88.89
9	33.33	38.89	38.89	37.04	16.67	11.11	16.67	14.82	44.44	27.78	37.89	50.00	33.33	33.33	37.80
10	50.00	33.33	33.33	38.89	22.22	22.22	38.89	27.78	22.22	27.78	33.33	38.89	11.11	38.89	28.70
11	33.33	27.78	33.33	31.48	5.56	33.33	50.00	29.63	38.89	33.33	38.89	38.89	50.00	22.22	37.04
12	33.33	27.78	55.56	38.89	22.22	0.00	0.00	7.41	33.33	33.33	38.89	38.89	44.44	38.89	37.96
13	33.33	50.00	66.67	50.00	33.33	38.89	27.78	33.33	16.67	33.33	44.44	22.22	33.33	38.89	31.48
14	72.22	66.67	66.67	68.52	100.00	100.00	100.00	100.00	77.78	83.33	77.78	77.78	55.56	83.33	75.93
Average	43.65	35.32	40.08	39.68	30.95	31.75	30.16	30.95	47.62	48.01	52.31	51.59	48.02	49.60	49.53

Note: Performance above the 88% mastery criterion in boldface

The average and standard error of all participants in all experimental stages can be seen in Figure 29 below.

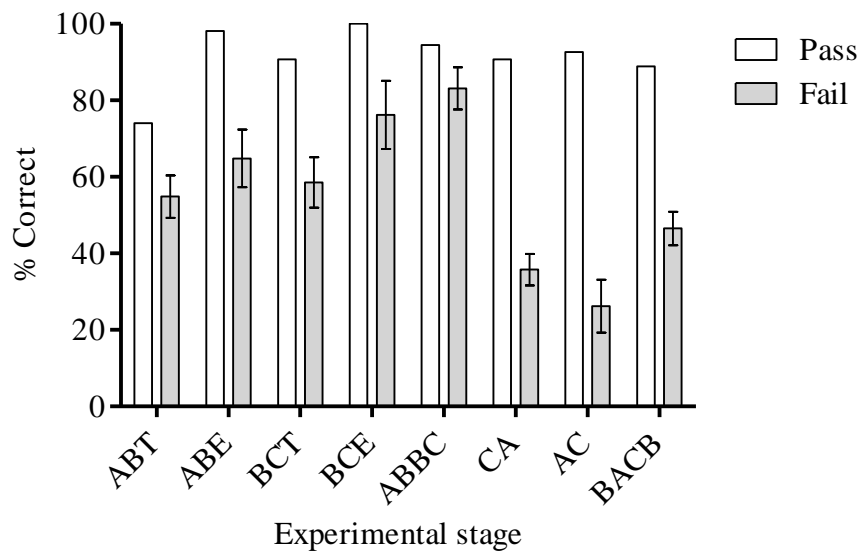


Figure 29. Average performance and standard error during all stages of Experiment 2.2 for all participants.

Discussion. Only one participant displayed equivalence in Experiment 2.2, substantially less than in Experiment 1.2, which also used abstract stimuli and Experiment 2.1 which employed the same protocol as Experiment 2.2 but iconic stimuli. If the protocols used in Experiments 1.2 and 2.2 are compared, this result might have been predicted based on the few participants that passed on the first exposure to the protocol in Experiment 1.2. The increased number of trials and fewer equivalence classes used in Experiment 2.2 were expected to allow more participants to display equivalence but it did not seem to have the desired effect. Comparing the results from the conditional discrimination in Experiments 1.2 and 2.2 is not possible because the difference in the protocols used yielded very different set of response pattern. Additionally, Experiment 1.2 yielded two relatively equal sized groups but Experiment 2.2 did not.

When comparing the results from the conditional discrimination training in Experiments 2.1 and 2.2, care must be taken because of the fact that only one participant

displayed equivalence in Experiment 2.2. When only comparing the Fail groups, some interesting similarities emerge. In Experiment 2.1, the Fail group averaged 61.11% correct during ABT, but in Experiment 2.2, this number was 54.84% correct. When Participant 10 (who performed the worst in this stage) is excluded, the average increases to 58.49% correct, almost identical to the results from Experiment 2.1.

In both experiments, the average performance improved by almost 10% in ABE, to 70.9% in Experiment 2.1 and to 64.81% in Experiment 2.2. Again, if the lowest performing participant is removed (Participant 7), the average in Experiment 2.2 increases to 69.6%, again being almost identical to Experiment 2.1.

In the BCT stage, the Fail group in Experiment 2.1 averaged 79.63% correct, but only 58.55% correct in Experiment 2.2. If the lowest performing participant (Participant 5) is removed, the average only increases to 62.35% correct which is 17.28 percentage points lower than in Experiment 2.1.

During BCE, performance in both Experiments improved, to 96.03% correct in Experiment 2.1 and to 76.21% in Experiment 2.2. The participant with the lowest score in BCE in Experiment 2.2 was Participant 5. If he is excluded from the calculations, the average increases to 81.17% correct.

In the final stage of the conditional discrimination training, the mixed ABBC stage, the Fail group in Experiment 2.1 displayed 93.25% correct responses, while the Fail group in Experiment 2.2 displayed 83.12% correct responses. In the ABBC stage in Experiment 2.2, Participant 10 displayed the lowest correct response score. If this participant's score is removed, the overall average is increased to 88.19% correct, which is close to the score from Experiment 2.1.

When comparing the performance of participants in experiments 2.1 and 2.2 during training, a different picture emerges. Overall, participants in Experiment 2.1 responded

70.91% correct during AB Training, but participants in Experiment 2.2 responded 56.22% correct during the same training stage. Additionally, 13 participants in Experiment 2.1 reached the mastery criterion on the last block of trials but only 6 participants reached that criterion in Experiment 2.2. This trend continued in the AB Extinction stage when the iconic group responded an average of 84.1% correct, and 14 participants reaching the mastery criterion but the abstract group 67.2% correct and only 6 participants reaching the mastery criterion. 14 participants in the iconic group reached the mastery criterion in the last block of AB Extinction but only 5 in the abstract group. Additionally, four participants showed a decrease in accuracy during the AB Extinction stage but none of the participants in the iconic group showed a similar response pattern. This would indicate that the AB connections were more firmly established in the iconic group than the abstract one.

Performance in the BC Training stage improved slightly in the iconic group from the previous stage, from 84.1% correct to 85.15% correct. This was not the case in the abstract group, where performance dropped slightly, to 60.85% correct during the BC Training stage. Also, the number of participants that reached the mastery criterion in the BC Training stage increased to 13 (85.15% overall) in the iconic group but dropped to 4 (60.85% overall) in the abstract group. The number of participants that reached the mastery criterion during the last block of BC Training increased to 16 in the iconic group but only to 6 in the abstract group. The rate of correct responding increased again during BC Extinction in both groups, to 96.62% correct in the iconic group and to 77.91% in the abstract group. This translated to all the participants in the iconic group reaching the mastery criterion during BC Extinction (both overall and during the last block of trials) but only 9 in the abstract group (but 10 during the last block of trials).

Finally, during AB/BC Training 16 out of the 17 participants in the iconic group reached the mastery criterion (both overall and during the last block of trials) and 9 in the abstract group (also both overall and during the last block of trials).

Overall, the results from the training stages in Experiments 2.1 and 2.2 are that participants exposed to abstract stimuli needed more trials to master the conditional discriminations than those exposed to iconic stimuli. Also, an interesting pattern emerges as the iconic group's rate of correct responses increases in each of the first four stages, displaying a slope like learning curve. However, the abstract group's performance drops sharply from AB Extinction to BC Training. This supports the idea that the easily nameable iconic stimuli greatly facilitate the conditional discrimination process, and thereby the formation of equivalence classes (Dickins, Bentall & Smith, 1993; Holth & Arntzen, 1998; Arntzen, 2004).

During derived responding, the type of stimuli also had an effect on participant performance. This could be due to a number of factors. One, participants might group together stimuli in a 'linear' fashion. In fact, some participants that displayed equivalence mentioned that they visualized the stimuli 'in a line', which helped them answer correctly when they were presented with C-A equivalence. This could be due to the fact that it might be easier to group together easily nameable stimuli, than it is abstract stimuli. Second, the ISI between the sample and comparison stimuli might affect the ability of participants to group the three stimuli together (see for example Leader, Barnes and Smeets, 1996). However, as this variable was not directly manipulated in Experiments 2.1 and 2.2, it is difficult to ascertain if the ISI had any effect on the yield in these experiments. This will be addressed in Experiments 3.1 and 3.2 below. Third, the use of keyboard responses might decrease the likelihood that participants display equivalence. As Arntzen (2004) pointed out, participants using a mouse as a response device might observe the comparison stimuli more than

participants using a keyboard as a response device. Also, the labels of the keys on the keyboard might be incongruent with class or stimulus names and therefore impede performance. This would especially be the case in the iconic group, but unlikely to play a part in the abstract group as the abstract stimuli would be unlikely to be named by the participants. However, when weighted against the clearer signal that a keyboard response delivers to the EEG as opposed to the mouse response, it was decided not to change the response device in the following experiments.

Because of the small number of participants that displayed equivalence in Experiment 2.2, data from participants in Experiment 2.1 will be combined with data from participants in Experiment 3.1 and data from Experiments 2.2 and 3.2 will be combined. These will then be compared in the Additional Analysis chapter below.

Chapter 4: Study 3

Experiment 3.1

Previous research has shown that the nameability of stimuli used in equivalence experiments can influence the outcome of the equivalence test (see Experiments 1.1 through 2.2 as well as Dickins, Bentall & Smith, 1993; Holth & Arntzen, 1998; Arntzen, 2000). Several authors have noted that increased inter stimulus and inter trial intervals (ISI and ITI) can positively influence the outcomes of equivalence tests (Leader, Barnes & Smeets, 1996). They argue that longer ISI and ITI will make it easier for participants to name the stimuli or stimulus classes, or even integrate the novel stimuli into already existing stimulus classes (Arntzen, 2000). However, increasing the time participants are in the EEG can negatively influence the quality and clarity of the EEG signal. As was mentioned above, long periods of concentration can cause fatigue effects in the EEG responses of participants, which can confound any possible effects of the experimental manipulations.

In order to simplify the protocol used, minor changes were made to the experimental protocol. First, the AB/BC mixed training stage was removed from the experiment. In previous experiments, no significant differences had been observed between the Pass and the Fail groups during the BCE and AB/BC stages. In fact, if the last trial block of BCE in Experiment 2.1 is examined almost all participants have reached the mastery criterion at that time. The mixed AB/BC training then becomes redundant and only serves to add more time to the experiments. Additionally, a 500 ms focus cross had been presented before the presentation of a sample in Experiment 2.1 and the trials ended with a 500 ms blank screen. The focus cross was now removed, and only the blank screen separated trials. All other parameters were identical in Experiments 2.1 and 3.1, to facilitate combining the data to create a larger data set in later stages in the analysis. To allow for a comparison of the experimental protocols used, both the stimuli used and the EEG analysis were identical to the

ones used in Experiment 2.1. The stimuli were easily nameable (iconic) stimuli which were previously used in experiments 2.1 and 3.1 as well as by Dickins et al. (2001). The EEG analysis was focused on spectral power during Baseline, A-B training (ABT), B-C extinction (BCE) and C-A testing (Equivalence).

Method.

Participants. Fifteen healthy adult human (5 male) participants took part in the study. All participants were between 18 and 20 years of age, were right handed and had normal or corrected to normal eyesight; none reported taking psychotropic medication, or having sustained traumatic brain injury. All participants were first year students at the National University of Ireland Galway and participated as part of their course credit. The study was approved by the NUI Galway Research Ethics Committee.

Apparatus. Apparatus was the same as in Experiment 2.1.

Stimuli. The stimuli and stimulus classes were the same as in Experiment 2.1.

General procedure. The participant recruitment, handedness assessment, demographic questionnaire and baseline were all identical to Experiment 2.1. Following the baseline, participants were exposed to the four stages of conditional discrimination training part of the experiment followed by the three stages of testing of derived relations (see Figure 30 below). No minimum correct criterion was required at any stage of the Experiment so participants advanced to the next stage irrespective of performance. After finishing the last Stage (B-A/C-B testing) the experiment was terminated and participants were not re-exposed to the experiment if they had performed poorly.

Stage one: AB training
54 trials (18 x A1-B1, 18 x A2-B2,
18 x A3-B3)

Stage two: AB extinction
54 trials (18 x A1-B1, 18 x A2-B2,
18 x A3-B3)

Stage three: BC training
54 trials (18 x B1-C1, 18 x B2-C2,
18 x B3-C3)

Stage four: BC extinction
54 trials (18 x B1-C1, 18 x B2-C2,
18 x B3-C3)

Stage five: CA Equivalence testing
54 trials (18 x C1-A1, 18 x C2-A2,
18 x C3-A3)

Stage six: AC Transitivity testing
54 trials (18 x A1-C1, 18 x A2-C2,
18 x A3-C3)

Stage five: BA/CB Symmetry
testing
108 trials (18 x B1-A1, 18 x B2-A2,
18 x B3-A3, 18 x C1-B1, 18 x C2-
B2, 18 x C3-B3)

Figure 30. Schematic outline of Experiment 3.1.

EEG data preparation. See Experiment 2.1.

Conditional discrimination training. Conditional discriminations, necessary for the formation of the three three-member equivalence classes in the task, were trained using a delayed matching to sample (MTS) linear protocol in four stages, each with 54 trials. In Stage 1 the following conditional discriminations were trained: $A1 \rightarrow B1$, $A2 \rightarrow B2$ and $A3 \rightarrow B3$. The trial started with a blank screen for 500 ms, followed by a sample which stayed on the screen for 1000 ms. The sample was then replaced by three comparisons which stayed on the screen for until a response was made by the participant. The location of the correct and incorrect B stimuli was randomly counterbalanced. Participants chose the comparison by pressing the '1', '2' or '3' buttons on the number pad on the keyboard. '1' corresponded to

the B stimulus on the left, '2' corresponded to the B stimulus in the middle and '3' corresponded to the B stimulus on the right. Following their response, feedback, either 'Correct' or 'Incorrect' was presented in 48 pt. Times new roman font at the centre of the screen for 1000 ms followed by the blank screen which signalled the start of the next trial. Stage 2 was identical to Stage 1, except no feedback was given to participants and each trial was therefore shortened by 1000 ms. In Stage 3 the following conditional discriminations were trained: $B1 \rightarrow C1$, $B2 \rightarrow C2$ and $B3 \rightarrow C3$. Trials in Stage 3 were otherwise identical to those in Stage 1. Stage 4 was identical to Stage 2, except no feedback was given to participants on their performance and trials were therefore 1000 ms shorter.

Testing derived relations. All testing stages were designed with the same parameters as Stages 2 and 4 in the conditional discrimination training with regards to timing and inter stimulus interval. Stage 5 was a mixed testing block, consisting of 54 trials which tested all equivalence relations ($C1 \rightarrow A1$, $C2 \rightarrow A2$ and $C3 \rightarrow A3$). Stage 6 was a mixed testing block, consisting of 54 trials which tested all transitive relations ($A1 \rightarrow C1$, $A2 \rightarrow C2$ and $A3 \rightarrow C3$). Finally, Stage 7 was a mixed testing block, consisting of 108 trials which tested all symmetrical relations ($B1 \rightarrow A1$, $B2 \rightarrow A2$, $B3 \rightarrow A3$, $C1 \rightarrow B1$, $C2 \rightarrow B2$ and $C3 \rightarrow B3$).

Results.

Behavioural results. Fifteen participants were recruited for the experiment, 5 displayed equivalence during the C-A (Equivalence) stage. Participants that scored 88% correct (48 out of 54 trials) or higher in the equivalence were initially considered to have passed the equivalence test. The participants were assigned to one of two groups, Pass and Fail, based on their performance during the equivalence test. This 88% mastery criterion was used to determine participants' performance in all stages of the experiment. P18 was considered to belong to the Pass group as his performance during the last 36 trials of Equivalence was 97.22% correct. However, during the first 18 trials, the participant only

scored 50% correct so his average score during the equivalence test stage was only 81.48% correct. The participants overall performance was judged to be on par with participants in the Pass group and he was therefore included in that group. Percentage of correct responses for all 15 participants during all 7 stages of the experiment can be seen in Table 19.

Table 19

Percentage of correct responses during training and testing stages in Experiment 3.1

	AB Train	AB Ext	BC Train	BC Ext	CA	AC	BA/CB
1	92.59	100.00	87.04	100.00	96.29	98.15	98.15
2	38.89	27.78	59.26	79.63	35.19	33.33	57.41
3	96.30	100.00	96.29	100.00	92.59	100.00	98.15
4	74.07	90.74	92.59	98.15	94.44	96.29	88.89
5	79.63	98.15	90.74	98.15	14.82	1.85	90.74
6	75.93	96.30	94.44	100.00	98.15	100.00	100.00
7	77.77	94.44	68.52	94.44	88.89	90.74	92.59
8	31.48	25.93	88.89	96.30	3.71	1.85	20.37
9	64.81	96.29	83.33	94.44	27.78	31.48	54.63
10	42.59	20.37	92.59	100.00	27.78	33.33	59.26
11	66.66	98.15	85.19	100.00	1.85	1.85	79.63
12	87.04	100.00	79.63	98.15	12.97	5.56	67.59
13	27.78	31.48	40.74	40.74	31.48	33.33	26.85
14	85.18	100.00	79.63	100.00	31.48	31.48	46.30
15	85.18	100.00	100.00	100.00	81.48	98.15	100.00

Note: Performance above the 88% mastery criterion in boldface

As in Experiment 2.1, the performance of the two groups was fairly distinguishable throughout the experiment (see Figure 31 below). During ABT, the Pass group performed responded 83.64% correct, and the fail groups' response was 58.23%, correct. Only two (13.3%) participants performed to the 88% criterion in ABT, both of which were members of the Pass group, but the performances ranged from 75.93% to 96.30% correct. In the Fail group, the correct responses ranged from 27.78% to 87.04% correct. When participants performance is broken down into three separate trial blocs (see Table 20 below) a similar pattern emerges as during Experiment 2.1. Only one participant (Participant 3) reached the mastery criterion in the first block of training trials. In the second block seven participants

reached the mastery criterion and finally in the third and last block 11 out of the 15 participants reached the mastery criterion.

Both groups' performance improved during ABE as the Pass group averaged 96.91% correct (ranging from 94.44% to 100% correct) and the Fail group averaged 66.46% correct (ranging from 20.37% to 100% correct). Overall, eleven participants reached the mastery criterion after 54 ABE trials. All of those eleven had reached the mastery criterion during the last block of the ABT stage. Of the four participants that did not reach the mastery criterion during the ABE stage, three showed a decrease in performance throughout the stage.

The Pass groups' performance dropped slightly during BCT, as the group averaged 89.81% correct, ranging from 68.52% correct to 100% correct. The Fail group averaged 77.78% correct, ranging from 40.74% correct to 92.59% correct, and improving slightly. Overall, the rate of correct responses during BCT dropped slightly from the ABE stage, but was still higher than during the ABT stage. Seven participants reached the mastery criterion during this stage. When the stage is broken down, only three participants reached the mastery criterion in the first block, twelve in the second block and fourteen in the third and last block.

Both groups' performance improved in the BCE stage, Pass to 98.77% and ranging from 94.44% to 100% correct, and Fail to 89.71%, ranging from 40.74% to 100% correct. During BCE thirteen participants reached the mastery criterion in the first block of trials and remained at that level throughout the stage. Two participants (2 and 13), did not reach the mastery criterion in any of the BCE trial blocks, although Participant 2 performed significantly better than P13 (79.63% correct vs. 40.74% correct).

Overall, the Pass group outperformed the Fail group in all stages of Training, although the difference was very small during BCE. The Pass groups' performance improved from training to extinction in both ABT and BCT, but the Fail group showed a steady improvement throughout the 4 training stages, gradually improving until its performance was

close to that of the Pass group. Eleven of the 15 participants responded over the 88% correct criterion on the AB extinction and 96.62% on the BC extinction. Additionally, when compared to Experiment 2.1, the overall response patterns in Experiment 3.1 were similar. During ABT, very few participants reached the mastery criterion, then an improvement in overall performance during ABE. A slight drop was then observed in performance during BCT, followed by another improvement during BCE.

Table 20

Breakdown of individual performance during ABT, ABE, BCT, BCE and AB/BC in Experiment 3.1

Ptp. No	ABT				ABE				BCT				BCE			
	1-18	19-36	37-54	AVRG	55-72	73-90	91-108	AVRG	109-126	127-144	145-162	AVRG	163-180	181-198	199-216	AVRG
1	77.78	100.00	100.00	92.59	100.00	100.00	100.00	100.00	61.11	100.00	100.00	87.04	100.00	100.00	100.00	100.00
2	50.00	33.33	33.33	38.89	44.44	27.78	11.11	27.78	33.33	55.56	88.89	59.26	83.33	77.78	77.78	79.63
3	88.89	100.00	100.00	96.30	100.00	100.00	100.00	100.00	94.44	94.44	100.00	96.29	100.00	100.00	100.00	100.00
4	38.89	83.33	100.00	74.07	88.89	88.89	94.44	90.74	83.33	94.44	100.00	92.59	94.44	100.00	100.00	98.15
5	50.00	88.89	100.00	79.63	100.00	100.00	94.44	98.15	72.22	100.00	100.00	90.74	100.00	94.44	100.00	98.15
6	50.00	77.78	100.00	75.93	100.00	88.89	100.00	96.30	88.89	94.44	100.00	94.44	100.00	100.00	100.00	100.00
7	44.44	94.44	94.44	77.77	100.00	88.89	94.44	94.44	44.44	72.22	88.89	68.52	100.00	88.89	94.44	94.44
8	27.78	11.11	55.56	31.48	38.89	27.78	11.11	25.93	83.33	88.89	94.44	88.89	100.00	100.00	88.89	96.30
9	66.67	33.33	94.44	64.81	100.00	94.44	94.44	96.29	61.11	94.44	94.44	83.33	100.00	94.44	88.89	94.44
10	27.78	33.33	66.67	42.59	44.44	16.67	0.00	20.37	83.33	100.00	94.44	92.59	100.00	100.00	100.00	100.00
11	44.44	61.11	94.44	66.66	100.00	100.00	94.44	98.15	55.56	100.00	100.00	85.19	100.00	100.00	100.00	100.00
12	61.11	100.00	100.00	87.04	100.00	100.00	100.00	100.00	50.00	88.89	100.00	79.63	100.00	94.44	100.00	98.15
13	33.33	16.67	33.33	27.78	27.78	38.89	27.78	31.48	44.44	38.89	38.89	40.74	22.22	55.56	44.44	40.74
14	61.11	94.44	100.00	85.18	100.00	100.00	100.00	100.00	38.89	100.00	100.00	79.63	100.00	100.00	100.00	100.00
15	61.11	94.44	100.00	85.18	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Average	52.22	68.15	84.81	68.39	82.96	78.15	74.81	78.64	66.29	88.15	93.33	82.59	93.33	93.70	92.96	93.33

Note: Performance above the 88% mastery criterion in boldface

A very clear difference in the groups' performance during all three testing stages can be seen in Figure 31 below. During equivalence, the Pass group responded 91.97% correctly, but the Fail groups' correct responses were only 20.78%. The Pass groups' performance improved during Transitivity, scoring 97.22% correct, as the Fail groups' performance dropped slightly to 19.34%. The groups' performances were somewhat more similar during Symmetry, as the Pass groups' performance was 96.3% and the Fail groups' performance was 55.86% correct. This improvement in performance in the Fail group can mostly be attributed to Participants 5 and 11, whose performance was 90.74% and 79.63% respectively during Symmetry. If those two participants are removed from the group, the group performance drops to 47.49% correct, increasing the group difference even further. Even if participants in the Fail group did not reach the predetermined criterion of 88% in the Symmetry stage, there seems to be at least some level of recognition of the stimulus pairs previously learned. Participants in the Fail group responded anywhere from 20.37% to 90.74% correct during this stage.

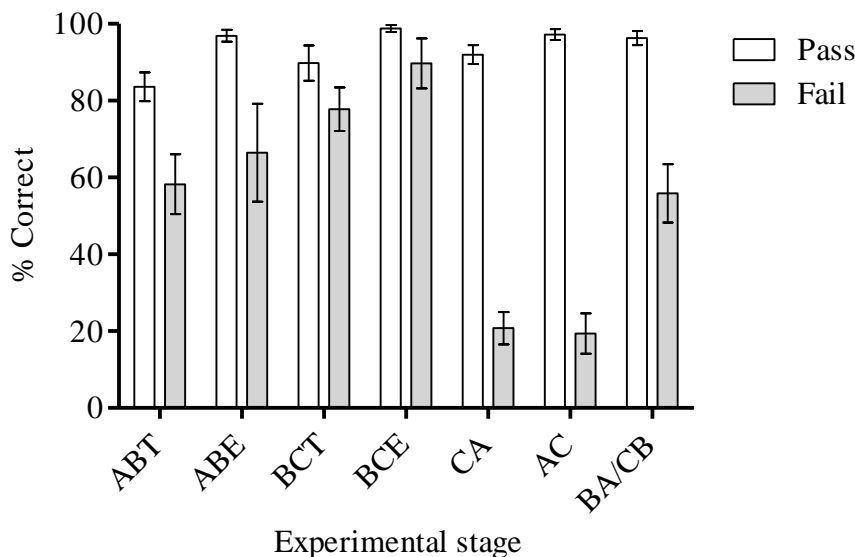


Figure 31. Average performance and standard error during all stages of Experiment 3.1 for both Pass and Fail groups.

A block by block analysis in Table 21 below reveals that only three participants (1, 3 and 6) displayed equivalence in the first block of Equivalence (CA) testing. In the second block, Participant 4, 7 and 15 display delayed emergence of equivalence as they all respond in accordance with equivalence during this block. In the third block, Participant 7 shows a minor deterioration in performance, dropping slightly below the mastery criterion. In the Transitivity (AC) testing stage the same six participants that displayed equivalence, responded in accordance to Transitivity. In the Symmetry stage Participant 5 who did not display either equivalence or transitivity, responded in accordance with Symmetry and was the only participant in the Fail group to reach the mastery criterion in any of the six trial blocks.

Table 21

Breakdown of individual performance during Equivalence (CA), Transitivity (AC) and Symmetry (BACB) in Experiment 3.1

Ptp. No	CA				AC				BACB						
	217-233	234-252	253-270	AVRG	271-288	289-306	307-324	AVRG	325-342	343-360	361-378	379-396	397-414	415-432	AVRG
1	94.44	94.44	100.00	96.29	100.00	94.44	100.00	98.15	100.00	94.44	100.00	100.00	94.44	100.00	98.15
2	50.00	27.78	27.78	35.19	38.89	27.78	33.33	33.33	50.00	61.11	61.11	61.11	55.56	55.56	57.41
3	88.89	100.00	88.89	92.59	100.00	100.00	100.00	100.00	100.00	94.44	100.00	100.00	94.44	100.00	98.15
4	83.33	100.00	100.00	94.44	94.44	100.00	94.44	96.29	100.00	100.00	88.89	88.89	77.78	77.78	88.89
5	27.78	16.67	0.00	14.82	0.00	5.56	0.00	1.85	77.78	94.44	88.89	88.89	100.00	94.44	90.74
6	94.44	100.00	100.00	98.15	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
7	83.33	100.00	83.33	88.89	88.89	94.44	88.89	90.74	94.44	88.89	88.89	100.00	100.00	83.33	92.59
8	5.56	0.00	5.56	3.71	5.56	0.00	0.00	1.85	5.56	27.78	22.22	22.22	27.78	16.67	20.37
9	22.22	27.78	33.33	27.78	33.33	27.78	33.33	31.48	50.00	61.11	72.22	38.89	55.56	50.00	54.63
10	27.78	22.22	33.33	27.78	33.33	33.33	33.33	33.33	55.56	50.00	50.00	66.67	61.11	72.22	59.26
11	5.56	0.00	0.00	1.85	0.00	5.56	0.00	1.85	72.22	83.33	72.22	83.33	83.33	83.33	79.63
12	27.78	5.56	5.56	12.97	11.11	5.56	0.00	5.56	72.22	55.56	72.22	77.78	61.11	66.67	67.59
13	44.44	27.78	22.22	31.48	22.22	33.33	44.44	33.33	16.67	27.78	33.33	22.22	38.89	22.22	26.85
14	33.33	27.78	33.33	31.48	27.78	33.33	33.33	31.48	38.89	27.78	61.11	27.78	72.22	50.00	46.30
15	50.00	100.00	94.44	81.48	100.00	94.44	100.00	98.15	100.00	100.00	100.00	100.00	100.00	100.00	100.00
Average	49.26	50.00	48.52	49.26	50.37	50.37	50.74	50.49	68.89	71.11	74.07	71.85	74.81	71.48	72.04

Note: Performance above the 88% mastery criterion in boldface

EEG data. EEG data was analyzed for all 6 participants that displayed equivalence in the 5th stage of the Experiment. Chosen for analysis were Baseline, A-B Training, B-C Extinction and C-A Equivalence. The statistical tests used on the EEG data were the same as the ones used in Experiment 2.1 (see p. 81).

Delta (0.5-3.5 Hz). The regions were also compared along the Sagittal and Coronal lines using a 4x3x3 repeated measures three-way ANOVA (as in Experiment 2.1). A large Stage effect was found, ($F_{3, 15} = 47.377, p < .001, \eta_p^2 = .905$), as well as Coronal effect, ($F_{2, 10} = 10.979, p = .003, \eta_p^2 = .687$, see Figure 32). A small, but significant Stage x Coronal interaction effect was also found, ($F_{2, 30} = 3.961, p = .005, \eta_p^2 = .442$). During Baseline, delta power was strongest in the Frontal regions, lower in the Central regions and the Posterior regions showing the weakest delta power. Frontal power was strongest in all three task conditions, but during Training Central delta power was lower than both Frontal and Posterior delta power, during Extinction delta power in all three Coronal areas was relatively even and finally during Equivalence, Frontal and Posterior delta power was close to identical and Central delta power significantly lower.

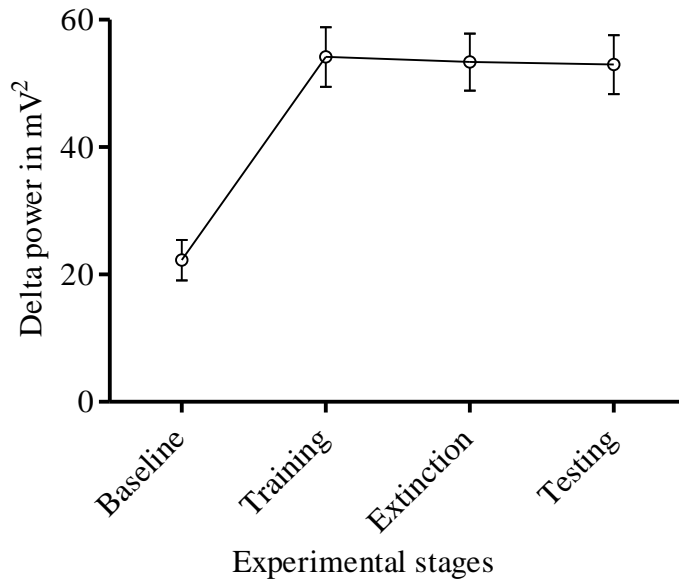


Figure 32. Grand average and standard error of EEG delta power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 3.1.

As was predicted, the lowest delta power was registered during Baseline, lower than any of the three task conditions. No significant difference was found between the three task stages. As in Experiment 2.1, a repeated measures one-way ANOVA was performed on each of the nine brain regions to assess any Stage related changes in EEG power. The F , η_p^2 and p values and degrees of freedom for each of the individual region ANOVAs are summarized in Table 22 below.

Table 22

Summary of F, p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 3.1 at each of the brain regions for the delta frequency.

Delta (0.5-3.5 Hz)				
Brain region	F	p	η_p^2	df
LF	49.314	<.001*	.908	3,15
MF	10.624	.001*	.680	3,15
RF	13.074	<.001*	.723	3,15
LC	14.491	<.001*	.743	3,15
MC	2.715	.082	.352	3,15
RC	12.162	<.001*	.709	3,15
LP	13.681	<.001*	.732	3,15
MP	64.259	<.001*	.928	3,15
RP	106.934	<.001*	.955	3,15

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

*Significant effect following Holm-Bonferroni corrections

Average delta power values and standard errors in all 9 regions can be seen in Figure 33 below. All regions except Mid-Central showed a significant effect of Stage on delta power. Following Holm-Bonferroni corrections, Baseline power was found to be significantly lower than power during Training, Extinction and Equivalence at all regions (all $p = .039$ or less) except Mid-Central. Unlike the Extinction delta power peak that was seen in Experiment 2.1, very little differences were found between the regions during the three task stages.

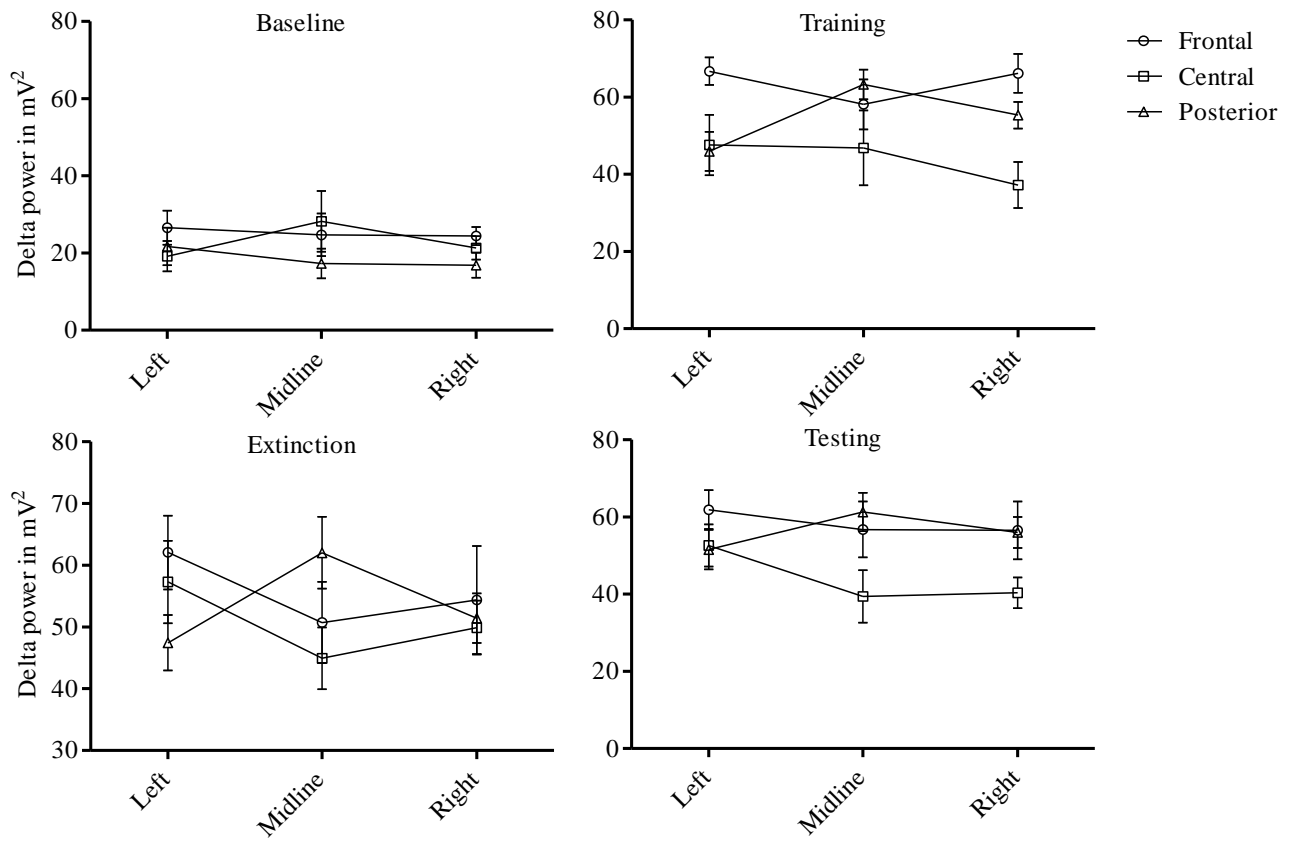


Figure 33. Average delta power values in μV^2 and standard error in all 9 regions used for analysis during Baseline, Training, Extinction and Testing.

Theta (3.5-7.5 Hz). A 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed to assess any effects of Stage on theta power on the Coronal and Sagittal planes. A Stage effect was found on overall theta power, ($F_{3, 15} = 6.109, p = .006, \eta_p^2 = .550$), due mostly to Baseline theta power being lower than any of the task stages (see Figure 34). However, none of the pairwise comparisons survived Holm-Bonferroni corrections. Mauchly's test indicated that the assumption of sphericity had been violated for Sagittal effects (chi-square = 10.650), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (epsilon = .518). The results show a significant Sagittal effect, ($F_{1, 5.2} = 15.760, p = .001, \eta_p^2 = .759$), as Midline theta power was higher than both Left ($p = .014$) and Right ($p = .006$) regions, regardless of Stage. A Stage x Coronal

interaction effect was found, ($F_{6, 30} = 3.477, p = .010, \eta_p^2 = .410$). During Baseline, theta power was evenly distributed along the Coronal axis, with no significant differences between Frontal, Central and Posterior regions. This was not the case throughout the task, as during Training Frontal theta power was lower than Central theta power, and Posterior theta power was higher than either Central or Frontal Theta power. During Extinction and Equivalence, Frontal and Posterior theta power remained fairly stable, only increasing slightly. However, power in the Central regions increased from Training to Extinction and again during Equivalence. Additionally, the variation in power decreased in the Central regions during Equivalence, but increased in Frontal and Posterior regions (see Figure 34 below).

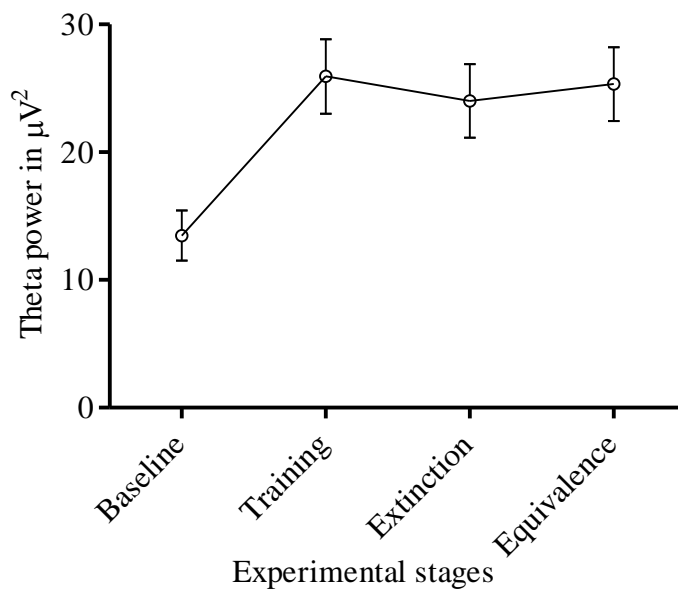


Figure 34. Grand average and standard error of EEG theta power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 3.1.

A repeated measure one-way ANOVA was performed on each of the nine brain regions to further explore any effects of Stage on theta EEG power. The results can be seen in Table 23 below.

Table 23

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 3.1 at each of the brain regions for the theta frequency

Theta (3.5-7.5 Hz)				
Brain region	F	p	η_p^2	df
LF	.596	.627	.627	3, 15
MF	2.221	.128	.308	3, 15
RF	3.256	.051	.394	3, 15
LC	3.479	.043	.410	3, 15
MC	10.265	.019	.672	1.1, 5.5 ⁺
RC	8.921	.001*	.641	3, 15
LP	5.708	.008*	.533	3, 15
MP	5.243	.011	.512	3, 15
RP	6.127	.006*	.551	3, 15

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

* Significant effect following Holm-Bonferroni corrections

⁺ Degrees of freedom corrected with Greenhouse-Geisser

As can be seen in Table 23, Stage only had a significant effect on Central and Posterior regions, but no significant effect was found in the Frontal regions (see also Figure 35). In the Right-Central region Baseline theta power was significantly lower than Training ($p = .011$), Extinction (.019) and Equivalence (.001). No other significant differences were found in the Right-Central region.

Following Holm-Bonferroni corrections, no significant differences were found at the Left- and Right Posterior regions.

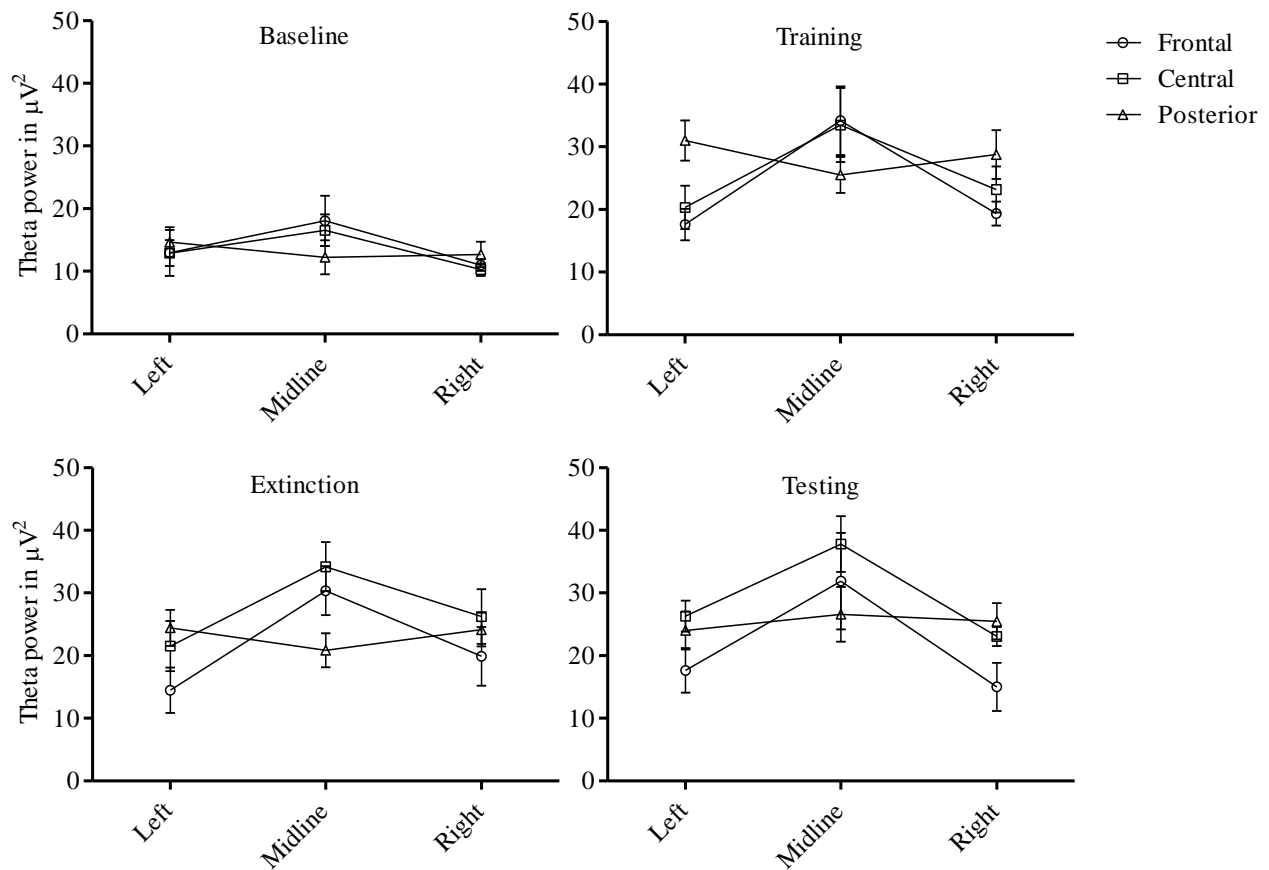


Figure 35. Average theta power values and standard error in all 9 regions used for analysis during Baseline, Training, Extinction and Testing in Experiment 3.1.

Alpha (7.5-12 Hz). A 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed to assess any effects of Stage on alpha power on the Coronal and Sagittal planes. The results (see figure 36) show that Stage had a significant effect on alpha power, ($F_{3, 15} = 48.486, p < .001, \eta_p^2 = .907$). Baseline alpha power was significantly higher than Training ($p < .001$), Extinction ($p = .001$) and Equivalence ($p = .001$). A small, but significant, effect was found for Coronal activity ($F_{2, 10} = 4.286, p = .045, \eta_p^2 = .462$), as alpha power was weakest in the Frontal regions, then slightly higher in the Central regions and highest in the Posterior regions, regardless of Stage. A Stage x Coronal interaction was also found, ($F_{6, 30} = 7.330, p < .001, \eta_p^2 = .594$). During Baseline alpha power was highest in the Posterior regions, followed by the Frontal regions and the Central regions having the

lowest alpha power. During Training, the lowest alpha power was in the Frontal regions, but no difference between the Central and Posterior regions. Extinction saw Posterior alpha power increase, but Central and Frontal regions had similar alpha power. Finally, during Equivalence, Frontal alpha power was again lower than both Central and Posterior who were almost equal.

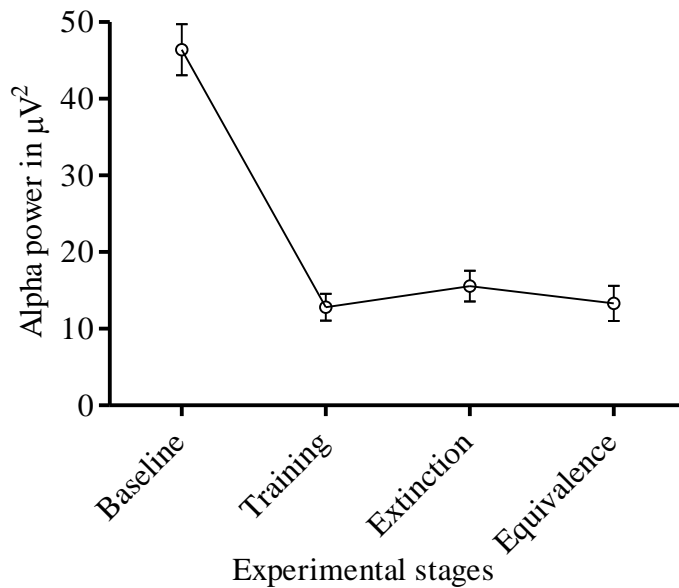


Figure 36. Grand average and standard error of EEG alpha power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence. In Experiment 3.1.

A repeated measure one-way ANOVA was performed on each of the nine brain regions in an attempt to isolate the location of the effect. The results can be seen in Table 24 below.

Table 24

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 3.1 at each of the brain regions for the alpha frequency

Alpha (7.5- 12 Hz)				
Brain region	F	p	η_p^2	df
LF	44.858	.001*	.900	1.1, 5.5 ⁺
MF	13.617	.010*	.731	1.2, 5.8 ⁺
RF	35.135	<.001*	.875	3, 15
LC	44.979	<.001*	.900	3, 15
MC	12.242	<.001*	.710	3, 15
RC	26.920	<.001*	.843	3, 15
LP	22.291	<.001*	.817	3, 15
MP	66.378	<.001*	.930	3, 15
RP	46.931	<.001*	.904	1.3, 6.4 ⁺

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

* Significant effect following Holm-Bonferroni corrections

⁺ Degrees of freedom corrected with Greenhouse-Geisser

Average alpha power values and standard error in all 9 regions can be seen in Figure 37 below. Alpha power was higher during Baseline at all location than during any of the Task conditions. Additionally, alpha power during Extinction was significantly higher than during Training in the Right-Posterior ($p = .007$) region.

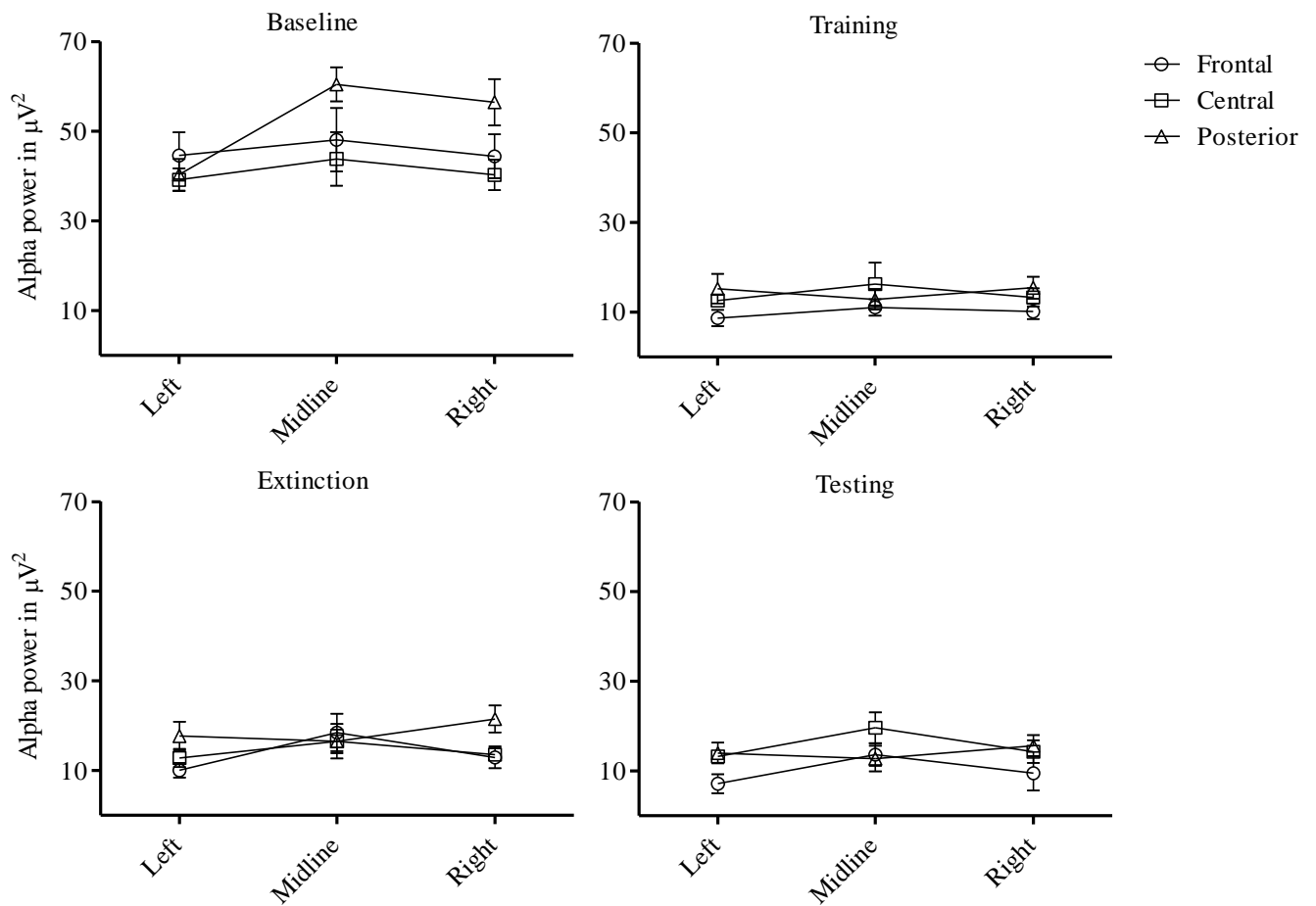


Figure 37. Average alpha power values in μV^2 and standard error in all 9 regions used for analysis during Baseline, Training, Extinction and Testing in Experiment 3.1.

Although alpha power is relatively equal throughout the scalp during all Task stages, the Left-Frontal region does seem to have lower alpha than adjacent regions during Training and Testing. This lowering of alpha power could be indicative of increased activity at this region during those Stages. However, this must be interpreted with caution, due to the small sample size.

Beta (12-30 Hz). To assess any cross regional effects, a 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed. Mauchly's test indicated that the assumption of sphericity had been violated ($\chi^2 = 16.659$), therefore degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity ($\epsilon = .364$).

Stage had a significant effect on overall beta power, ($F_{1.092, 5.462} = 9.479, p = .023, \eta_p^2 = .655$).

Changes in beta power were similar to changes in alpha power, as Baseline beta power was higher than beta power during any of the Task conditions (see Figure 38 below).

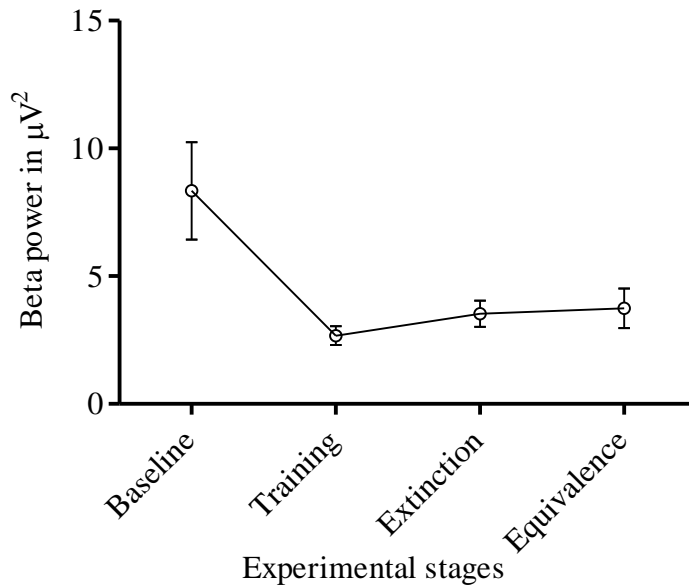


Figure 38. Grand average and standard error of EEG beta power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 3.1.

To further investigate the stage effects found in the 4x3x3 ANOVA, a one-way repeated measures ANOVA was conducted on each of the nine brain regions (see Table 25 below).

Table 25

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 3.1 at each of the brain regions for the beta frequency

Beta (12 – 30 Hz)				
Brain region	F	p	η_p^2	df
LF	7.963	.002*	.614	3, 15
MF	7.959	.036	.614	1, 5.1 ⁺
RF	4.431	.079	.470	1.2, 5.8 ⁺
LC	5.015	.062	.501	1.2, 6.1 ⁺
MC	5.337	.011	.516	3, 15
RC	8.423	.029	.627	1.1, 5.5 ⁺
LP	7.709	.033	.607	1.1, 5.6 ⁺
MP	7.179	.003*	.590	3, 15
RP	9.370	.026	.652	1.1, 5.3 ⁺

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

* Significant effect following Holm-Bonferroni corrections

⁺ Degrees of freedom corrected with Greenhouse-Geisser

In the Left-Frontal region, Baseline beta power was significantly higher than both Training ($p = .004$) and Equivalence ($p = .018$). No other effects were found in that region.

In the Mid-Posterior region, Baseline beta power was significantly higher than Training ($p = .012$), Extinction ($p = .045$) and Equivalence ($p = .026$). No other effects were found in that region. Average beta power values and standard error in all 9 regions can be seen in Figure 39 below

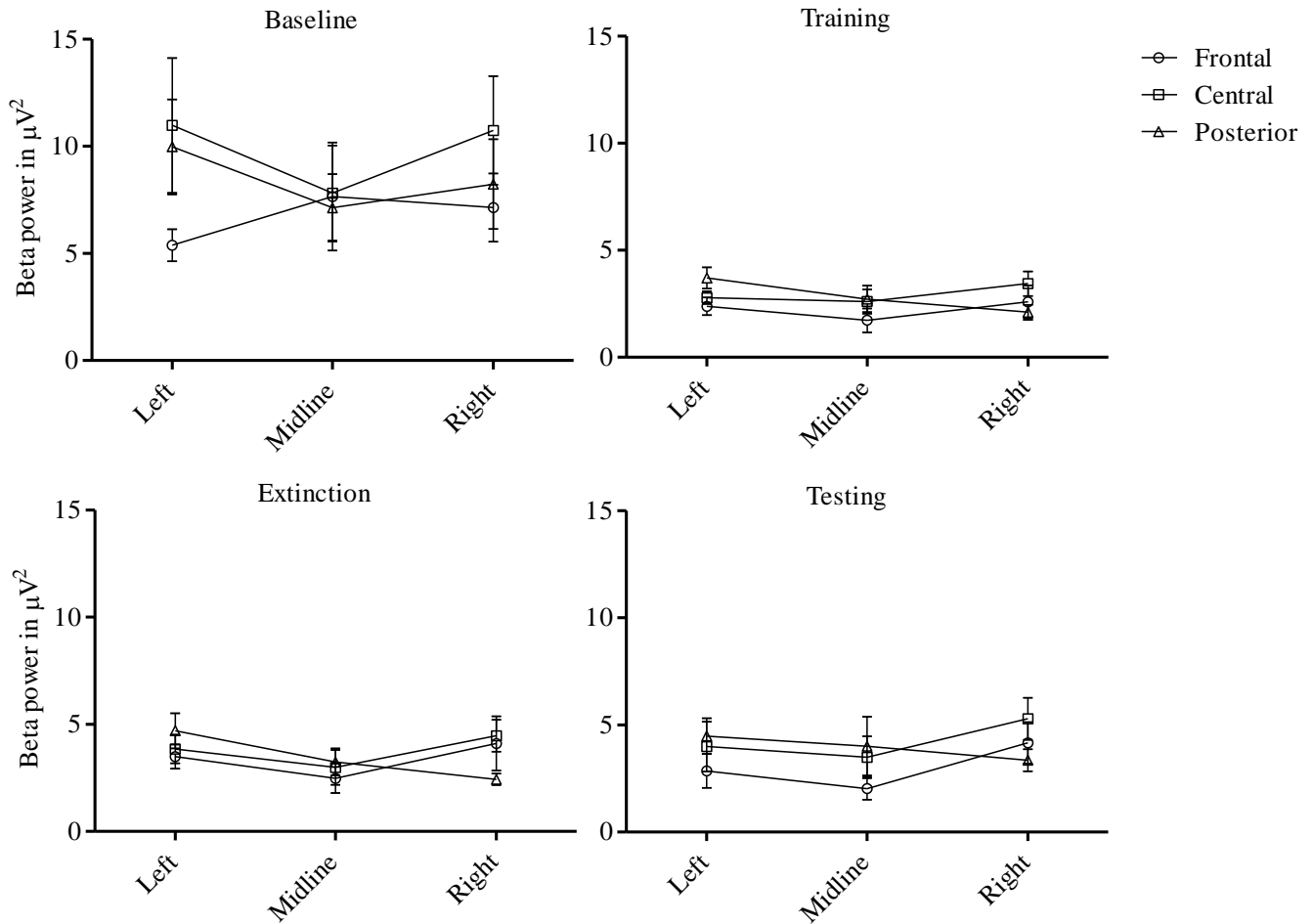


Figure 39. Average beta power values in μV^2 and standard error in all 9 regions used for analysis during Baseline, Training, Extinction and Testing in Experiment 3.1.

Gamma (30-40 Hz). To assess any cross regional effects, a 4 (Stage) x 3 (Coronal) x 3 (Sagittal) repeated measures three-way ANOVA was performed. No Stage effects were found (see Figure 40 below). However, small but significant Coronal, ($F_{2,10} = 5.452, p = .025, \eta_p^2 = .522$), and Sagittal, ($F_{2,10} = 9.879, p = .004, \eta_p^2 = .664$), effects were found. The Coronal effect was due to gamma power being significantly lower in Posterior regions than both Central ($p = .014$) regions. The Sagittal effect was due to gamma Midline power being significantly lower than both Left ($p = .005$) and Right ($p = .018$) gamma power. Additionally, a Stage x Coronal, ($F_{6,30} = 4.047, p = .004$), and a small Stage x Sagittal, ($F_{6,30} = 2.682, p = .03, \eta_p^2 = .447$), interaction effects were found. During Baseline, gamma

power was highest in the Central and Frontal regions, closely followed by the Posterior regions. During Training, gamma power in the Frontal and Central regions remained at almost Baseline levels but fell in Posterior regions, and remained low in Posterior regions throughout the experiment. During Extinction, gamma power in the Central regions fell to similar levels as in Posterior regions but an increase was observed in the Frontal regions. Finally, during Equivalence, gamma power in the Frontal regions remained at high levels, while gamma power in the Central regions increased nominally but remained at Extinction levels in the Posterior regions.

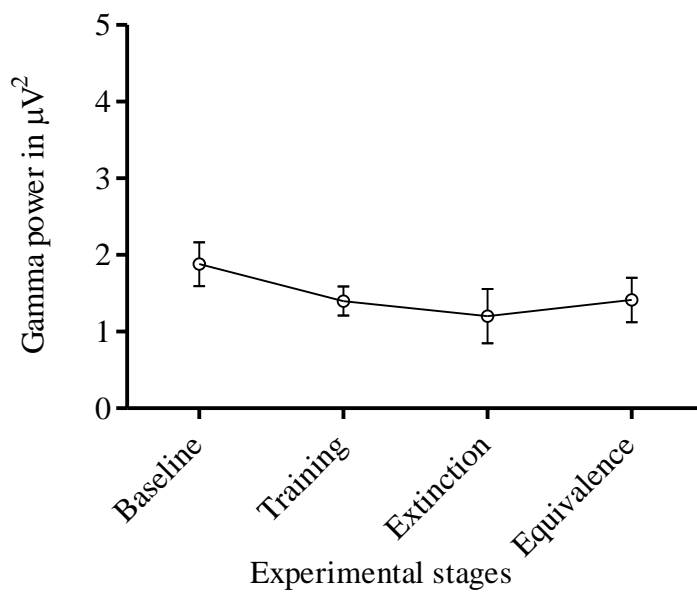


Figure 40. Grand average and standard error of EEG gamma power in μV^2 during Baseline, A-B Training, B-C Extinction and C-A Equivalence in Experiment 3.1.

No significant differences were found in gamma power between the Task stages. A repeated measure one-way ANOVA was performed on each of the nine brain regions in an attempt to isolate any localized effects of Stage in gamma power. As can be seen in Table 26 below, none of the differences were significant following Holm-Bonferroni corrections.

Table 26

Summary of F , p and η_p^2 values and degrees of freedom for one way repeated-measures ANOVA on the effect of Stage in Experiment 3.1 at each of the brain regions for the gamma frequency

Gamma (30-40 Hz)				
Brain region	F	p	η_p^2	df
LF	.656	.592	.116	3, 15
MF	3.788	.033	.431	3, 15
RF	.916	.391	.155	1.2, 5.6 ⁺
LC	4.452	.020	.471	3, 15
MC	4.442	.020	.470	3, 15
RC	3.660	.037	.423	3, 15
LP	4.585	.068	.478	1.3, 6.4 ⁺
MP	1.911	.171	.277	3, 15
RP	2.545	.095	.337	3, 15

LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

⁺ Degrees of freedom corrected with Greenhouse-Geisser

Discussion. The results in Experiment 3.1 were broadly similar to those in Experiment 2.1. The Pass and Fail groups could be differentiated clearly during the ABT and ABE stages. That difference then becomes negligible during the BCT and BCE stages, and then re-appears during all three Testing stages. However, as before, the difference in the test stages is smallest during the BA/CB stage.

Participants in Experiment 3.1 performed slightly worse than participants in Experiment 2.1 overall. However, when the Pass and the Fail groups are compared across experiments, another pattern emerges. During Training, Pass participants in Experiment 3.1 did slightly better than Pass participants in Experiment 2.1. The opposite applied to the Fail group, as the Fail group in Experiment 2.1 slightly outperformed the Fail group in

Experiment 3.1. However, this difference is most likely due to the different number of participants in the two experiments.

Little can be asserted about the EEG activity during Experiment 3.1 due to the few participants that displayed equivalence. However, the general trends can be compared to Experiment 2.1 and evaluated. Delta power during Baseline was substantially lower than during any of the Task stages, and overall delta power did not show any changes in power throughout the task. For individual regions, only the Right-Central region showed any noteworthy fluctuations throughout the task as a delta power during Extinction is somewhat higher than during both Training and Testing. This is interesting as the strongest effect in delta in Experiment 2.1 was the increase in overall power during Extinction. However, the increase observed here was not in the same regions as observed in previous experiments. In Experiment 1.1, an increase from Baseline to Task conditions was primarily observed in the Midline regions and in Experiment 2.1, the increase was at the Left-Frontal, Mid-Central and all three Posterior regions. It is unclear why this increase during delta does not appear in the same region in the two experiments, although the smaller sample size in Experiment 3.1 is one possible reason. It is conceivable that the participants that displayed equivalence in the latter experiment were better prepared or that the different outcomes might have been due to a selection effect and that different participants participated in the two experiments. The possibility of different participants in the experiments is unlikely, as no baseline differences were found between the two groups. It is also possible that the protocol itself played a role in this difference, although that is unlikely, as the segments chosen for analysis were the same length in both experiments and did not differ in terms of stimuli presented.

The overall results for theta power were similar in Experiments 2.1 and 3.1; Baseline theta displayed the lowest theta amplitude, followed by Extinction and finally Training and Equivalence displaying largely similar power. The main difference in the overall theta power

between the experiments is the variation in power. Greater variation was observed in theta power in Experiment 2.1, than in Experiment 3.1. However, as was mentioned before, the shorter experiment with shorter processing times might have given the advantage to participants with propensity for conditional discrimination learning. The Pass group in Experiment 2.1 might therefore have included participants of more variable ability than the Pass group in Experiment 3.1. Of the individual region results, the Right-Frontal, Mid-Frontal and Mid-Central regions were of specific interest (see for example Caplan & Glaholt, 2007; Caplan, Glaholt & McIntosh, 2008, Sauseng & Klimesch, 2008). The increase in activity in the Right-Central area from Baseline to Training was substantial. This increased power was sustained during Extinction, before falling to near Baseline levels during Equivalence but no significant differences were found between the task stages. This could be due to Frontal activity being involved in working memory behaviour, such as rehearsal, whilst Equivalence is not. Although the completion of the Equivalence task is contingent on learning information in previous stages, it does require a different set of skills to complete. The activity in the Mid-Frontal and Mid-Central areas, which is increased in all task conditions following Baseline, could be activity that is not specifically task related, or activity which is needed in categorization and verbal tasks. As both the Training and Testing would include a level of categorization and verbal abilities, it is not unlikely that this region would be involved in both tasks.

Overall alpha power was similar in both Experiment 2.1 and Experiment 3.1, a high Baseline power followed by an even alpha power throughout all three task stages. There was also less variation in the alpha power in participants in Experiment 3.1 than in Experiment 2.1. The average Baseline alpha power was also slightly higher in Experiment 3.1 than in Experiment 2.1. This might be an indication that the Pass group in Experiment 2.1 included participants that would not have passed if they had been exposed to the protocol used in

Experiment 3.1. Hoptman & Davidson (1998), Klimesch (1999) and Klimesch et al. (1994) have reported that Baseline EEG power can predict performance on tasks of memory and verbal fluency. If baseline EEG is different between the Pass and Fail groups, and if the Pass group in Experiment 2.1 includes members of more varying capacity than the Pass group in Experiment 3.1, it is not unlikely that there would be more variability in the Baseline in the Pass group in Experiment 2.1. As Klimesch (1999) points out, there is a large individual difference in alpha power. Therefore, it is more likely that this difference between the groups is due to the small sample size in Experiment 3.1. The distribution of alpha throughout the task stages was similar in Experiments 2.1 and 3.1, however, as with alpha power during Baseline, there was less variability in alpha power in the latter experiment than in the former. Alpha power during Extinction was somewhat higher than both Training and Testing, which indicates that Extinction needs less attention from the participants than the other test stages.

Beta power showed similar changes between stages in Experiment 2.1 and 3.1, however, the variation in power was more in the latter experiment than the former, which is contrary to delta, theta and alpha frequencies. Overall, if the Stage effect on beta power was only due to Baseline power being higher than during task stages, but no difference between was found between the stages. Just as in alpha, a decrease in beta power indicates synchronisation of activity. Beta power increased in the Left-Frontal and Mid-Posterior regions, which could be attributed to the participants verbalizing the pairs presented to them in order to correctly respond to them later (see Hwang et al., 2005). The decrease in beta power in posterior regions from Baseline to task was also expected (see Papousek & Schuter, 2004), as this posterior drop in beta power has been associated with operant conditioning.

Although Stage did not have a significant effect on gamma power, the power curve in Figure 34 is similar to the one seen in Figure 20 from Experiment 2.1. Baseline gamma was lower in Experiment 3.1, but overall the results are similar. The distribution of effects is

different between the two experiments. The only region that Stage had an effect on in both experiments was the Mid-Central region. In Experiment 2.1, Stage had the most significant effects in the Posterior regions; however, the most prominent changes in Experiment 3.1 were in the Central regions. When interpreting results for the gamma frequencies, the main problem was that the majority of research on gamma activity has focused on event-related changes, not FFT analysis. However, Canan Basar-Eroglu et al. (1996) have postulated that the gamma-band rhythm is an important, universal operator in brain function, which is distributed to many subsystems of the brain. Therefore, task related gamma activity could be related to complex tasks such as tests of derived relations.

Experiment 3.2

The slight protocol changes in Experiment 3.1 from the one used in Experiment 2.1 necessitated that all elements of the study be replicated, including the presentation of abstract stimuli. The results were expected to be similar from the ones obtained from Experiment 2.2, however, due to the overall similarity of the protocols the aim was to merge the participants that displayed equivalence in Experiments 2.2 and 3.2 into one group in the Additional Analysis chapter. The stimuli used were abstract stimuli previously used in Experiments 1.2 and 2.2, arranged in 3 three-member equivalence classes.

Method.

Participants. Fourteen healthy adult human (6 male) participants took part in the study. All participants were between 17 and 20 years of age, were right handed and had normal or corrected to normal eyesight; none reported taking psychotropic medication, or having sustained traumatic brain injury. All participants were first year students at the National University of Ireland Galway and participated as part of their course credit. The study was approved by the NUI Galway Research Ethics Committee.

Apparatus. Apparatus was the same as in Experiments 2.1, 2.2 and 3.1.

Stimuli. The same abstract stimuli and stimulus classes were used in Experiment 3.2 as previously in Experiment 2.2.

General procedure. The participant recruitment, handedness assessment, demographic questionnaire and baseline were all identical to Experiments 2.1-3.1.

EEG data preparation. See Experiment 2.1.

Conditional discrimination training. Conditional discrimination training and equivalence testing were identical to Experiment 3.1.

Results. Fourteen participants were recruited for the experiment, and only one, Participant 3, displayed Equivalence. Thus, no EEG analysis was conducted on the current sample at this time. The results from all stages of the Experiment can be seen in Table 27 below.

Table 27

Percentage of correct responses during training and testing stages in Experiment 3.2

	AB Train	AB Ext	BC Train	BC Ext	CA	AC	BA/CB
1	66.67	98.15	85.19	100.00	25.93	31.48	21.30
2	53.70	92.59	62.96	92.59	53.70	35.19	70.37
3	83.33	92.59	72.22	96.30	90.74	92.59	78.70
4	27.78	46.30	70.37	98.15	24.07	9.26	45.37
5	44.44	92.59	61.11	66.67	25.93	22.22	56.48
6	83.33	98.15	79.63	98.15	31.48	33.33	50.93
7	33.33	66.67	94.44	100.00	42.59	33.33	66.67
8	42.59	85.19	74.07	96.30	42.59	33.33	70.37
9	72.22	96.30	35.19	24.07	5.56	0.00	31.48
10	55.56	94.44	70.37	98.15	42.59	35.19	68.52
11	33.33	35.19	16.67	18.52	29.63	11.11	16.67
12	74.07	100.00	75.93	98.15	5.56	1.85	40.74
13	22.22	37.03	29.63	18.52	27.78	16.67	21.30
14	37.04	61.11	85.18	100.00	31.48	0.00	35.18

Note: Performances above the 88% mastery criterion in boldface

In the AB Training stage, participants averaged 52.12% correct, but when Participant 3 is removed the average increased to 59.71% correct. The lowest score in this stage was

22.22% correct but Participant 13. Only two participants were close to the 88% correct criterion during this stage, Participant 3 which also displayed Equivalence in Stage 5, and Participant 6, both scoring 83.33% correct. When examined block by block (see Table 28 below), performance during ABT in Experiment 3.2 was similar to that observed in Experiment 2.2. No participant reached the mastery criterion in the first block, and only two in the second block. In the third block, five participants reached the mastery criterion.

All participants' performance improved ABE, as the group average increased to 78.31% correct, ranging from 35.19% to 100% correct. If Participant 3 is excluded, the group average only drops to 77.21% correct. Interestingly, five participants outperformed Participant 3 in this stage, which could indicate that performance in the training stages does not predict performance on the Equivalence test. Eight of the fourteen participants scored above the 88% criterion during this stage, and one (Participant 12) scored 100% correct. When the results were broken down into blocks of 18 trials, the results were similar to those seen in the overall averages for the ABE stage. The eight participants that reached the overall mastery criterion also reached that criterion in each of the three blocks. The response patterns of the six participants that did not reach the mastery criterion were somewhat different. Participant 7 showed an increase in correct responses from the last ABT block to the first ABE block. His performance improved again in the second block when he reached the mastery criterion. However, in the last block his performance dropped sharply (from 88.89% correct to 38.89% correct). Participant 8 appears to have shown delayed learning, as his performance first drops slightly between the last ABT block to the first ABE block (72.22% correct to 66.67% correct) and then increases to 88.89% and finally to 100% correct in the last block of trials.

As in previous experiments, average performance dropped during BCT compared to ABE. The average correct score was 65.21% (64.67% if P3 is excluded), ranging from

16.67% correct to 94.44% correct. As in the ABE stage, a number of participants outperformed Participant 3 in this stage. This was also evident in the trial breakdown. In the first block of trials, only one participant (Participant 7) reached the mastery criterion. In the second block, five participants reached the mastery criterion and finally in the third and last block eight participants reached the mastery criterion. It is worth noting that Participant 3 that did display equivalence did not reach the mastery criterion until the last block of trials.

Performance improved again during BCE, when the group average was 78.97% correct (77.64% if P3 is excluded), ranging from 18.52% to 100% correct. In this stage, Participant 3 was outperformed by 7 other participants. The trial breakdown shows that ten participants reached the mastery criterion in the first block of BCE trials, and that the same participants reached the mastery criterion at the end of the stage. The participants that did not reach the mastery criterion all showed a decline in performance from the first to the third block of trials.

Table 28

Breakdown of individual performance during ABT, ABE, BCT and BCE in Experiment 3.2

Ptp. No	ABT				ABE				BCT				BCE			
	1-18	19-36	37-54	AVRG	55-72	73-90	91-108	AVRG	109-126	127-144	145-162	AVRG	163-180	181-198	199-216	AVRG
1	27.78	77.78	94.44	66.67	100.00	100.00	94.44	98.15	61.11	94.44	100.00	85.19	100.00	100.00	100.00	100.00
2	33.33	38.89	88.89	53.70	88.89	94.44	94.44	92.59	50.00	44.44	94.44	62.96	88.89	88.89	100.00	92.59
3	66.67	83.33	100.00	83.33	88.89	88.89	100.00	92.59	44.44	83.33	88.89	72.22	100.00	94.44	94.44	96.30
4	33.33	22.22	27.78	27.78	44.44	55.56	38.89	46.30	33.33	77.78	100.00	70.37	100.00	100.00	94.44	98.15
5	27.78	38.89	66.67	44.44	88.89	100.00	88.89	92.59	61.11	55.56	66.67	61.11	77.78	66.67	55.56	66.67
6	66.67	88.89	94.44	83.33	100.00	100.00	94.44	98.15	77.78	77.78	83.33	79.63	100.00	94.44	100.00	98.15
7	27.78	16.67	55.56	33.33	72.22	88.89	38.89	66.67	94.44	94.44	94.44	94.44	100.00	100.00	100.00	100.00
8	16.67	38.89	72.22	42.59	66.67	88.89	100.00	85.19	55.56	83.33	83.33	74.07	94.44	100.00	94.44	96.30
9	33.33	88.89	94.44	72.22	94.44	94.44	100.00	96.30	38.89	33.33	33.33	35.19	22.22	27.78	22.22	24.07
10	22.22	66.67	77.78	55.56	88.89	100.00	94.44	94.44	16.67	94.44	100.00	70.37	100.00	100.00	94.44	98.15
11	22.22	33.33	44.44	33.33	50.00	27.78	27.78	35.19	22.22	22.22	5.56	16.67	22.22	27.78	5.56	18.52
12	61.11	77.78	83.33	74.07	100.00	100.00	100.00	100.00	38.89	88.89	100.00	75.93	94.44	100.00	100.00	98.15
13	22.22	16.67	27.78	22.22	33.33	33.33	44.44	37.03	22.22	33.33	33.33	29.63	38.89	16.67	0.00	18.52
14	27.78	16.67	66.67	37.04	72.22	72.22	38.89	61.11	66.67	94.44	94.44	85.18	100.00	100.00	100.00	100.00
Average	34.92	50.40	71.03	52.12	77.78	81.75	75.40	78.31	48.81	69.84	76.98	65.21	81.35	79.76	75.79	78.97

Note: Performances above the 88% mastery criterion in boldface

As can be seen in Figure 42 below, the overall performance pattern in Experiment 3.2 was similar to that seen in previous experiments. Performance during ABT is fairly low, followed by an increase during ABE. Performance then drops slightly during BCT, but is still improved from ABT, and then increases again during BCE, which in this experiment was the last stage of training before testing commenced.

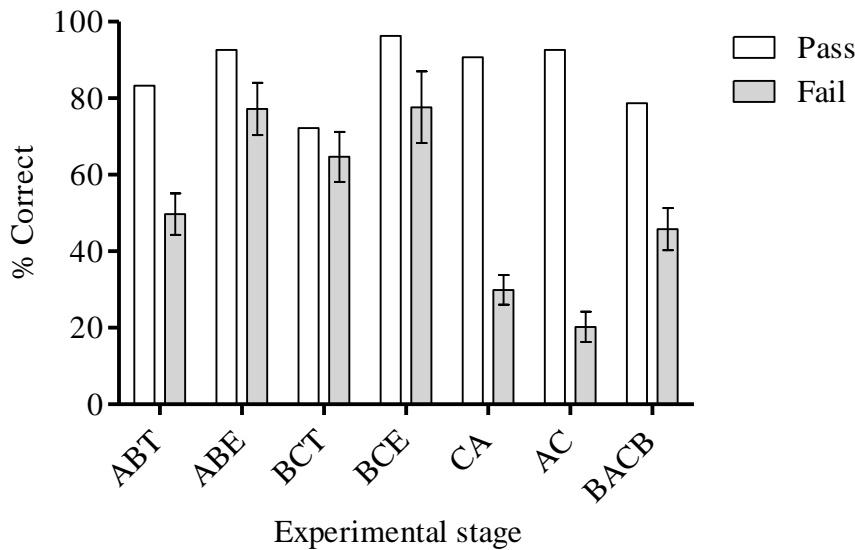


Figure 42. Average performance and standard error during all stages of Experiment 3.2 for all participants.

Table 29 below illustrates clearly the performance patterns in the three test stages in Experiment 3.2. Only one participant (Participant 3) displayed Equivalence and no other participant was close to him in performance. Participants 1, 4 and 6 showed some improvement from the first to the second block, but their performance did not improve enough for them to reach the mastery criterion, in fact Participants 1 and 6 both showed a decline in performance in the third block. All other participants showed evidence of extinction, as their performance gradually declined throughout the test stage.

During the Transitivity stage, Participant 3 responded perfectly (100% correct) in the first block of trials, before showing a decline in performance in the second block and not

responding to the mastery criterion. Finally, in the third block, his performance improved again and the overall performance during the stage was above the mastery criterion. The overall performance during the Transitivity stage was substantially lower than during Equivalence, dropping from 34.26% correct during Equivalence to 25.4% correct during Transitivity. Additionally, six participants (1, 2, 4, 5, 10, and 13) showed a marked decrease in correct responses while the rest did not show any changes. Finally, during Symmetry, none of the participants reached the mastery criterion overall and only Participant 8 reached the mastery criterion on one block of trials. Interestingly, the only participant that displayed equivalence (Participant 3) did not reach the mastery criterion in any of the Symmetry stages, although his average performance was still superior to any of the other participants.

Table 29

Breakdown of individual performance during Equivalence (CA), Transitivity (AC) and Symmetry (BACB) in Experiment 3.2.

Ptp. No	CA				AC				BACB						
	217-233	234-252	253-270	AVRG	271-288	289-306	307-324	AVRG	325-342	343-360	361-378	379-396	397-414	415-432	AVRG
1	5.56	38.89	33.33	25.93	33.33	27.78	33.33	31.48	22.22	22.22	33.33	11.11	27.78	11.11	21.30
2	66.67	61.11	33.33	53.70	38.89	33.33	33.33	35.19	66.67	66.67	83.33	55.56	77.78	72.22	70.37
3	94.44	88.89	88.89	90.74	100.00	83.33	94.44	92.59	83.33	83.33	72.22	83.33	77.78	72.22	78.70
4	16.67	27.78	27.78	24.07	27.78	0.00	0.00	9.26	44.44	38.89	44.44	50.00	50.00	44.44	45.37
5	33.33	33.33	11.11	25.93	50.00	11.11	5.56	22.22	44.44	38.89	61.11	66.67	50.00	77.78	56.48
6	22.22	38.89	33.33	31.48	33.33	33.33	33.33	33.33	50.00	44.44	55.56	61.11	50.00	44.44	50.93
7	55.56	33.33	38.89	42.59	33.33	33.33	33.33	33.33	72.22	66.67	77.78	55.56	55.56	72.22	66.67
8	61.11	33.33	33.33	42.59	33.33	33.33	33.33	33.33	88.89	72.22	72.22	61.11	61.11	66.67	70.37
9	16.67	0.00	0.00	5.56	0.00	0.00	0.00	0.00	27.78	33.33	22.22	44.44	27.78	33.33	31.48
10	55.56	38.89	33.33	42.59	38.89	33.33	33.33	35.19	66.67	83.33	72.22	66.67	61.11	61.11	68.52
11	44.44	16.67	27.78	29.63	5.56	22.22	5.56	11.11	33.33	11.11	22.22	0.00	22.22	11.11	16.67
12	11.11	5.56	0.00	5.56	0.00	0.00	5.56	1.85	27.78	33.33	44.44	38.89	55.56	44.44	40.74
13	27.78	27.78	27.78	27.78	27.78	11.11	11.11	16.67	16.67	38.89	22.22	16.67	11.11	22.22	21.30
14	27.78	33.33	33.33	31.48	0.00	0.00	0.00	0.00	44.44	27.78	44.44	27.78	44.44	22.22	35.18
Average	38.49	34.13	30.16	34.26	30.16	23.02	23.02	25.40	49.21	47.22	51.98	45.64	48.02	46.82	48.15

Note: Performances above the 88% mastery criterion in boldface

Discussion. As in previous experiments, the accuracy during the ABT stage in Experiment 3.2 was fairly low (52.12%). However, when each block is examined individually, a gradual learning can be observed. In the first block of training, response accuracy was 34.92%, in the second block 50.4% and finally in the third and last block response accuracy was up to 71.03% correct. Response accuracy continued to increase during the first two blocks of ABE, first to 77.78% correct and peaking at 81.75% correct. This was followed by a slight drop, to 75.4%, in the third block. This response pattern is slightly different than the one observed in the ABE block in Experiment 2.2. In Experiment 2.2 no participant showed an increase in response accuracy from the third block of ABT to the first block of ABE, but 10 of the 14 participants showed an increase in accuracy in Experiment 3.2.

Response accuracy fell slightly during BCT, to 48.81% correct in the first BCT block and 65.21% overall which is comparable to the results from Experiment 2.2. But as was observed in the AB stages in Experiment 3.2 and between BC stages in Experiment 2.2, response accuracy increased in the first block of BCE as compared to the third block of BCT. The average response accuracy in BCE in Experiment 3.2 was 78.97% compared to 77.91% in Experiment 2.2. Only one participant in each experiment displayed equivalence and the testing stages will therefore not be compared. In both experiments 2.1 and 3.1 participants demonstrated the conditional discrimination required during training but failed to demonstrate stimulus equivalence or symmetry relations.

These results from study 3 are similar to the ones observed in study 2 as the Pass and Fail groups' performance gradually converges and the Fail group displays a steady increase in accuracy throughout the four training stages but the Pass groups' performance decreases slightly in the Extinction stages. The overall result pattern observed in the training stages of Experiment 3.1 was comparable to that observed in Experiment 2.1. Participants displayed a

higher level of accuracy during the Extinction stages than during the Training stages and accuracy in the BCT stage was higher than during the ABT stage. In Experiment 3.1 participants showed a gradual increase in response accuracy, a response pattern which had been established in the three previous experiments. Additionally, the performance of the participants in the Abstract experiments (2.2 and 3.2) was not substantially different. The protocols used in the two studies were almost identical, apart from ISIs being shorter and the mixed AB/BC training stage was not presented in Study 3. The shortening of the protocol was meant to achieve two main goals. In order to minimize fatigue effects in the EEG, an experimental protocol needs to take as little time as possible. Additionally, the protocol must be useful in differentiating between participants that successfully display equivalence and those that do not. In the behavioural results in Table 19, a clear difference can be seen between the Pass and the Fail groups during tests of equivalence.

Chapter 5: Study 4

Additional analysis

Analysis of the results from Experiments 1.1 through 3.2 for the most part focused on the response patterns and EEG activity of participants that displayed Equivalence. This is in line with previous research on physiological activity during stimulus equivalence (see for example Barnes-Holmes et al., 2005a & 2005b; Dickins et al., 2001; Roche et al., 2004). However, the analysis done in previous chapters also included comparing physiological equivalence activity to that during conditional discrimination training in an attempt to contrast any equivalence-only activity with electrophysiological activity during cognitive effort in general. However, it is also important to analyze responses of participants that do not display equivalence, both behavioural and electrophysiological. By comparing activity in both Pass and Fail groups, it might be possible to identify electrophysiological patterns which could predict equivalence class formation during conditional discrimination training. If this is possible, the electrophysiological markers might be superior equivalence performance indicators than behavioural performance during the training stages. Participant data from Experiments 2.1 and 3.1 were combined to explore possible differences between Pass and Fail participants and data from all participants in Studies 2 and 3 were combined to explore the possible different effects of iconic and abstract stimuli.

Research so far has indicated that resting EEG measure can be used to predict general abnormal behavioural patterns, such as anxiety (Putman, 2011), depression (Blackhart, Minnix & Kline, 2006), age related cognitive decline (Rossini et al., 2008) and schizophrenia (Fleck et al., 2008), as well as performance on specific cognitive tests (Klimesch, 1999). Laukka, Järvillehto, Alexandrov & Lindqvist (1995) showed that theta amplitude in the Mid-Frontal area not only varied according to task difficulty, but also that participants that mastered the task faster showed a greater increase in theta from baseline to task. Çiçek &

Nalçacı (2001) also showed that both inter-hemispheric asymmetry and overall power of baseline alpha was indicative of performance on the Wisconsin Card Sorting Test (WCST). Participants that performed well on the WCST had greater overall resting alpha power than the participants that performed poorly on the test. Additionally, alpha power in the Left-Frontal region correlated positively with performance on the WCST. Jin, Kim, Kyung & Lee (2007), found differences in EEG activity between gifted and average students. In the study, gifted students were those that scored high on a test of creative thinking, rather than a traditional IQ test or school performance. The gifted students showed more overall activity in both hemispheres during baseline than the average students. This changed during the task, when EEG activity increased in the Right-Central, Temporo-Occipital and bilateral Pre-Frontal areas. The authors do not mention any one frequency measure, but rather measure overall electrophysiological activity.

The function, and even validity, of the gamma wave has been debated (see for example Rieder, Rahm, Williams & Keiser, 2011). However, with increasingly sophisticated experimental procedures and EEG analysis, it has become clear that gamma activity reported in experiments is not due to eye movement artefacts. Although most often correlated with perception and consciousness, Linkenkaer-Hansen, Nikulin, Palva, Ilmoniemi & Palva (2004) found that pre-stimulus gamma amplitude predicted perception of near threshold stimuli. Martinovic and colleagues (Martinovic, Gruber & Müller, 2007; Martinovic, Gruber, Hantsch & Müller 2008) found that gamma band activity was positively correlated with object classification, mostly in the prefrontal, central and posterior regions. However, none of the above mentioned research has used FFT analysis to investigate baseline gamma activity and its relation to task performance.

As previously mentioned, according to Basar et al (1999, 2000) the delta frequency might play a role in the integration of information. Delta power might therefore be different

in participants that display equivalence than in those that do not, as an important part of equivalence class formation is the integration of information from the conditional discrimination training stages. Also, Klimesch (1996, 1999) and Klimesch, Vogt & Doppelmayr (2000) found that baseline alpha activity was different between high and low performance on a memory task. The baseline alpha activity, specifically in the Left-Frontal area, could therefore be different in participants in the Pass and Fail groups respectively. Delta power should also be higher in participants that are exposed to iconic stimuli than in those exposed to abstract stimuli. If iconic stimuli facilitate naming of the individual stimuli (see for example Holth & Arntzen, 1998), it would be reasonable to assume that the assimilation of these stimuli into one class could constitute 'integration of information'. Therefore, delta power would be increased more in those participants that are exposed to the iconic stimuli.

The results so far indicate that even if participants receive the same amount of training and learn the conditional discriminations during the training stages, the type of stimuli plays a crucial role in their ability to display equivalence and how fast they acquire the equivalence relations (see Experiments 1.1 through 3.2). It is therefore reasonable to assume that the different types of stimuli also elicit a different EEG response. Hwang, Jacobs, Geller, Danker, Sekuler & Kahana (2005) found differences in EEG responses during tasks of verbal and non-verbal memory as measured in wavelet power at the Pz electrode. Hwang and associates used two types of a serial learning Sternberg task and found that both verbal and non-verbal stimuli elicited increases in theta power. Verbal stimuli also elicited stronger responses in the alpha and beta frequencies at the Pz electrode. This study also found increases in beta power in various electrodes across the scalp in response to verbal stimuli and more pronounced changes in the Frontal and Parietal Midline regions. Whereas previous studies (see Miller, 2007 for an overview) had identified memory related beta changes in the left frontal area,

Hwang et al. observed this effect bilaterally (that is in both left and right hemispheres), relative to baseline.

Gruber & Müller (2005) found that gamma responses are different after the presentation of familiar (pictures) stimuli on one hand and unfamiliar (abstract line drawings) stimuli on the other. Gruber & Müller presented each stimulus three times and found that familiar stimuli caused a gamma band response in the posterior regions. However, after repeated presentation of the same stimuli, the number of electrodes showing this effect reduced dramatically and the overall power displayed was significantly lowered. Unfamiliar stimuli, on the other hand, caused an increase in the gamma responses after just one presentation. This effect was reduced somewhat with repeated presentations, but not completely eliminated. The authors bring up the question of how many presentations are needed before the unfamiliar stimuli become familiar and will elicit a response similar to that of familiar images. Additionally, Gruber & Müller note that alpha did not show any differential response to familiar and unfamiliar stimuli, echoing results from Gruber, Keil & Müller (2001) which found effects in the alpha frequency in a paired associate learning task. Contrary to the results of Gruber & Müller (2005) and Gruber, Keil & Müller (2001), Busch Herrmann, Müller, Lenz & Gruber (2006) and Tallon-Baudry, Bertrand, Delpuech, & Pernier (1996; 1997) have reported that gamma band activity is reduced in response to unfamiliar or incoherent stimuli. However, the experimental protocols used in those experiments have involved a visual search paradigm, where participants are actively looking for a pattern in a visually ambiguous image which might account for the different findings.

Method. In order to further explore the EEG activity during equivalence and isolate activity that might be critical for equivalence responses, baseline EEG activity in both Pass and Fail groups in Experiments 2.1 and 3.1 was compared. To insure that the Pass and Fail groups in each experiment were compatible, their behavioural performance during CA

equivalence testing was compared using an independent samples t-test. That is, the performance of the Pass groups in Experiments 2.1 and 3.1 was compared as well as the performance of the Fail groups in Experiments 2.1 and 3.1. The independent samples t-test found no differences between the Pass groups in the two experiments ($t(14) = 852, p = .170$). A small difference was found between the Fail groups ($t(14) = .075, p = .030$). However, due to the small effect size the Pass groups were merged. The performance from the combined groups can be seen in Figure 43 below.

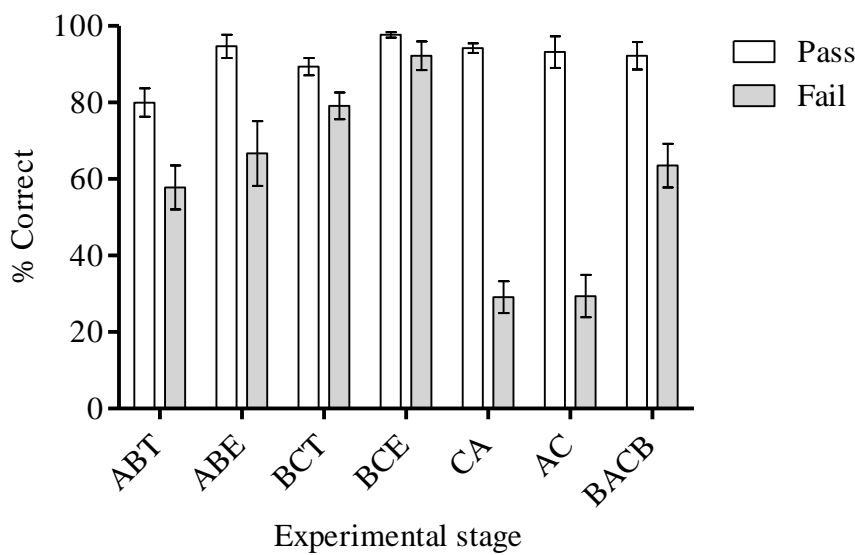


Figure 43. Combined behavioural results from Experiments 2.1 and 3.1

Thirty-two participants' EEG data was analysed for the comparison of the Pass and Fail groups, 16 participants in each group. To assess if any group differences existed between the Pass and Fail groups, their grand averages were first compared using a paired sample t-test. If a significant difference was detected, then further t-tests were conducted on the nine brain regions. No familywise corrections were used as those could result in insensitive t-tests and hide any noteworthy results.

Results.

Baseline differences. Grand average baseline comparisons (both eyes open and eyes closed) showed no significant differences between the groups in delta, theta, alpha and beta amplitudes.

The grand average gamma power of all the nine brain regions during eyes open was significantly ($t(30) = 5.24, p = .05$) higher in the Pass ($M = 5.07, SE = .36$) than the Fail ($M = 3.46, SE = .36$) group (see Figure 44 below).

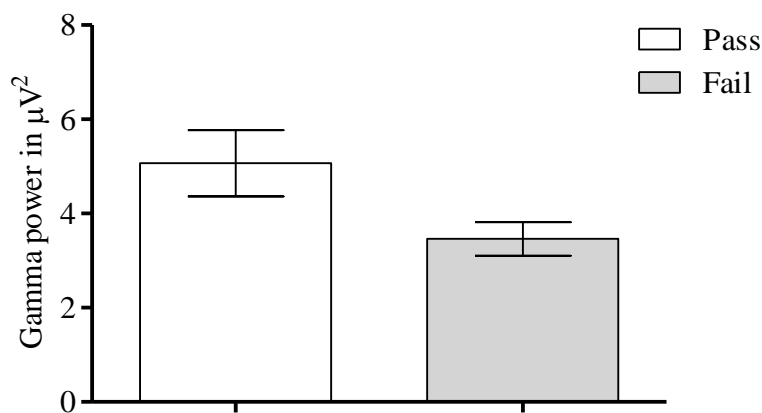


Figure 44: Differences in grand average gamma power during eyes open condition.

As can be seen in Figure 45 below, gamma power was significantly higher in the Pass than the Fail group in the Mid-Frontal, ($t(30) = 10.37, p = .003$), Mid-Central, ($t(30) = 2.30, p = .02$), Right-Central ($t(30) = 5.23, p = .049$) and Right-Posterior ($t(30) = 6.49, p = .028$) regions (see Table 30 for gamma results).

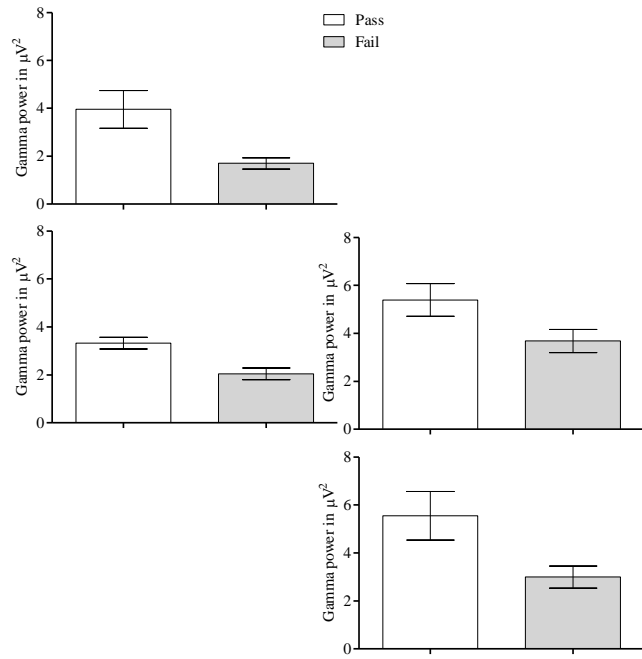
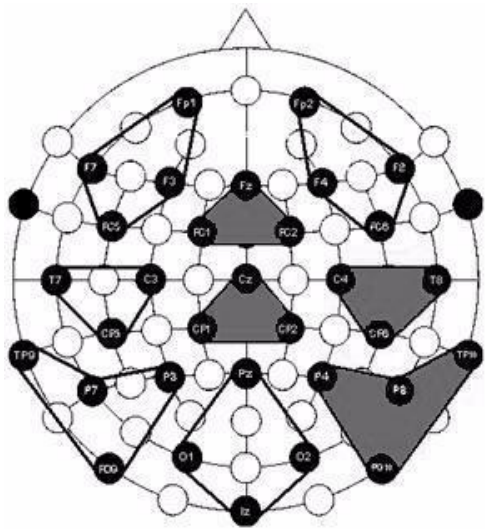


Figure 45: Differences in gamma power in the Mid-Frontal, Mid-Central, Right-Central and Right-Posterior (dark gray) regions during the eyes open condition.

Table 30

Average, SE and t-test results for differences in gamma values in all regions for both Pass and Fail groups

Region	Group	N	Mean	SE	t	df	Sig. (2-tailed)
LF	Fail	16	5.40	.79	-.59	30	.563
	Pass	16	6.29	1.29			
MF	Fail	16	1.70	.24	-2.72	30	.011
	Pass	16	3.96	.80			
RF	Fail	16	5.43	.72	-1.49	30	.146
	Pass	16	7.88	1.48			
LC	Fail	16	3.57	.53	-1.37	30	.180
	Pass	16	4.89	.79			
MC	Fail	16	2.05	.25	-2.46	30	.020
	Pass	16	3.33	.46			
RC	Fail	16	3.68	.48	-2.05	30	.049
	Pass	16	5.40	.68			
LP	Fail	16	3.53	.61	-.72	30	.477
	Pass	16	4.14	.59			
MP	Fail	16	2.79	.59	-1.43	30	.163
	Pass	16	4.17	.76			
RP	Fail	16	2.99	.46	-2.31	30	.028
	Pass	16	5.55	1.01			

Note: LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

Abstract vs. Iconic Differences. To assess any possible effects that stimulus types could assert on the EEG responses of participants during training, all four experiments were merged into one sample. The performance of participants in Experiments 2.2 and 3.2 during the first four training stages was compared to assure compatibility. No significant differences were found between the groups during any of the first four stages (all $p > .6$, see Table 31 below for M and SE).

Table 31

Average performance in % correct and standard error during AB and BC training in Experiments 2.2 and 3.2

	Experiment	N	Mean	SE
ABT	2.2	14	56.22	5.29
	3.2	14	52.12	5.56
ABE	2.2	14	67.20	7.38
	3.2	14	78.31	6.43
BCT	2.2	14	60.85	6.51
	3.2	14	65.21	6.07
BCE	2.2	14	77.91	8.41
	3.2	14	78.97	8.79

As can be seen in Figure 46 below, participants in all four experiments showed a similar response pattern throughout the four test stages. The ABT stage in all experiments is characterized by the lowest overall performance, followed by a sharp improvement in performance during ABE. Performance then drops again during BCT, followed by improvement during BCE, which in all experiments was better than performance during ABE. Therefore the stages used for comparison were only ABE and BCE which had the largest number of participants passing. As can be seen in the results from Experiment 2.2 and 3.2, the average performance in these two stages was similar to that observed in Experiments 2.1 and 3.1.

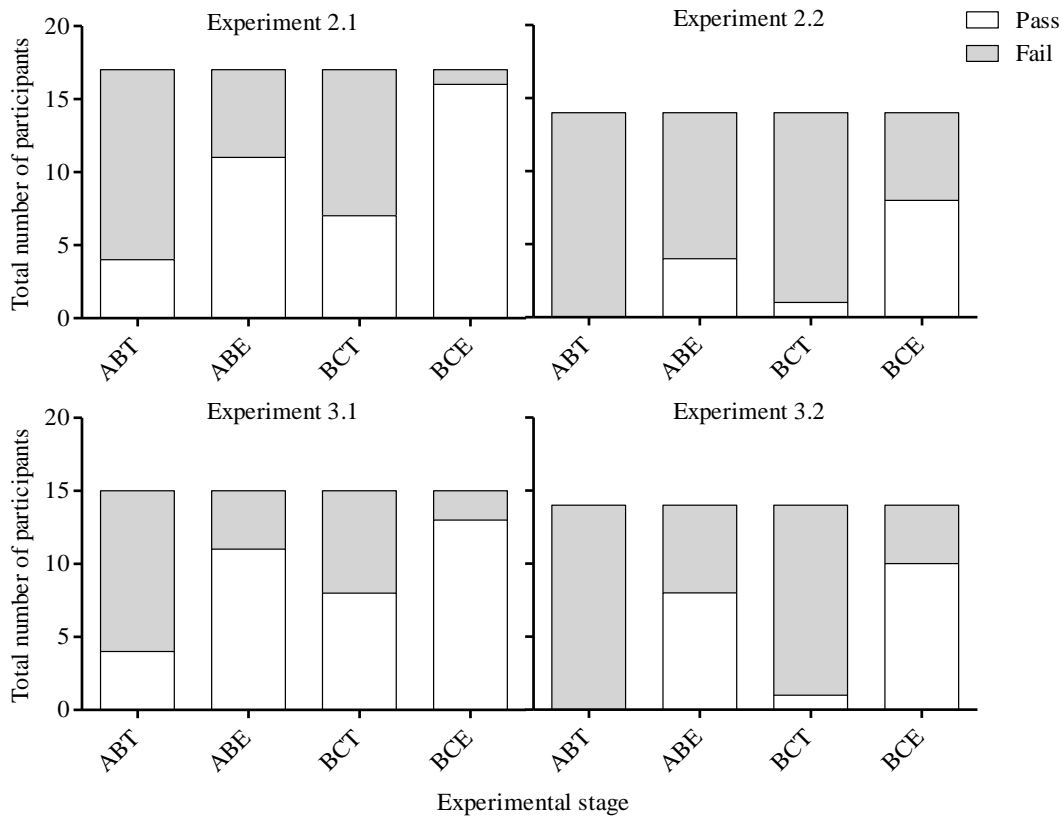


Figure 46: Participants performance during the first four stages of training in all experiments

Following Holm-Bonferroni corrections, differences were only found in gamma power between the Abstract and the Iconic groups at the Mid- Posterior region during both ABE ($t(33) = 24.18, p < .001$, Abstract ($M = 1.91, SE = .48$), Iconic ($M = .59, SE = .09$)) and BCE ($t(45) = 29.13, p < .001$), Abstract ($M = 2.24, SE = .60$), Iconic ($M = .73, SE = .11$)) stages (see Figure 47).

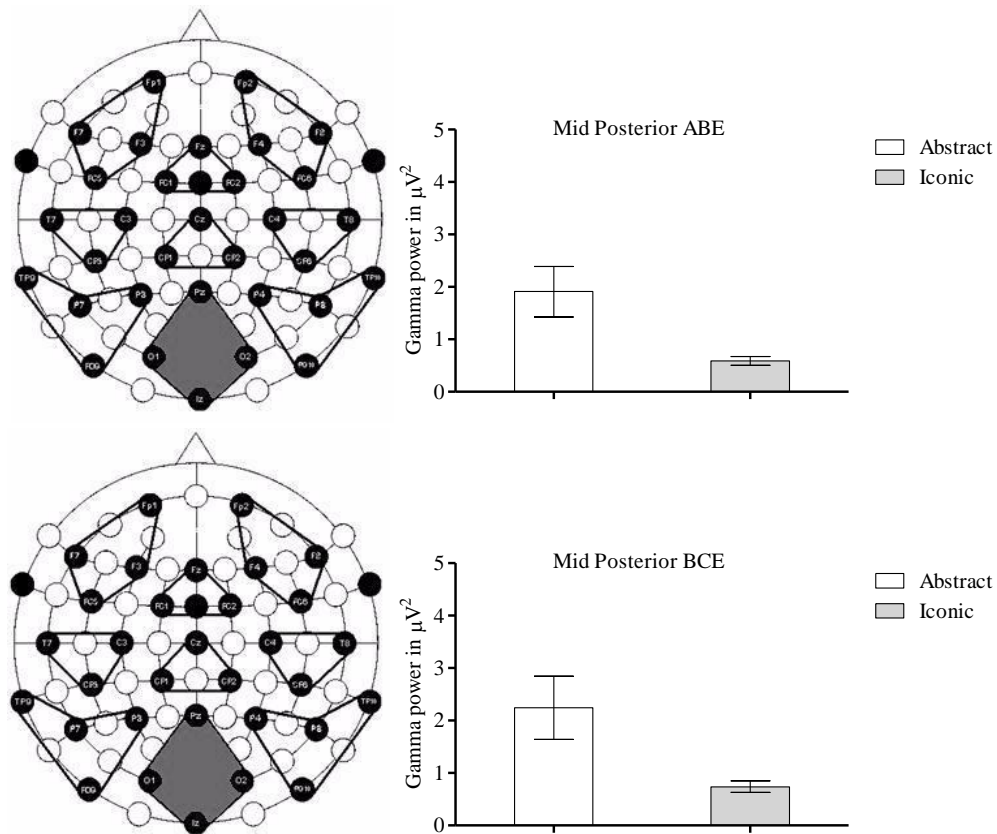


Figure 47: Differences in gamma power between the abstract and iconic groups in the Mid-Posterior region during ABE (upper panel) and in the Mid-Posterior (dark gray) regions during BCE.

Results for statistical tests for all nine regions during ABE and BCE stages in the gamma frequency can be seen in Table 32 below.

Table 32

Average, SE and t-test results for differences in gamma values in all regions for both Abstract and Iconic groups during ABE and BCE stages

Stage	Region	Group	N	Mean	SE	t	df	Sig (2 tailed)
ABE	LF	Abstract	12	2.3500	.57	1.657	33	.107
		Iconic	23	1.4961	.23			
	MF	Abstract	12	.8913	.12	1.954	33	.059
		Iconic	23	.6034	.08			
	RF	Abstract	12	2.7146	.64	.875	33	.388
		Iconic	23	2.1630	.31			
	LC	Abstract	12	3.1299	.63	2.606	33	.014
		Iconic	23	1.5831	.28			
	MC	Abstract	12	.5712	.06	1.361	33	.183
		Iconic	23	.4562	.05			
	RC	Abstract	12	2.5789	.35	.819	33	.419
		Iconic	23	2.1527	.33			
LP	Abstract	12	1.2284	.22	1.501	33	.143	
	Iconic	23	.9165	.10				
MP	Abstract	12	1.9088	.48	3.650	33	.001	
	Iconic	23	.5856	.08				
RP	Abstract	12	1.3915	.26	2.728	33	.010	
	Iconic	23	.7608	.10				
BCE	LF	Abstract	18	2.5063	.44	.289	45	.774
		Iconic	29	2.3377	.37			
	MF	Abstract	18	.7603	.10	-.743	45	.461
		Iconic	29	.9612	.20			
	RF	Abstract	18	3.0767	.50	-.552	45	.583
		Iconic	29	3.5087	.53			
	LC	Abstract	18	2.9322	.47	1.867	45	.068
		Iconic	29	1.8625	.34			
	MC	Abstract	18	.6971	.10	1.127	45	.266
		Iconic	29	.5449	.09			
	RC	Abstract	18	3.1950	.46	1.710	45	.094
		Iconic	29	2.1848	.37			
	LP	Abstract	18	1.3646	.22	1.765	45	.084
		Iconic	29	.9665	.11			
	MP	Abstract	18	2.2424	.60	3.061	45	.004
		Iconic	29	.7369	.11			
	RP	Abstract	18	1.6103	.27	2.676	45	.010
		Iconic	29	.9148	.12			

Note: LF = Left-Frontal, MF = Mid-Frontal, RF = Right-Frontal, LC = Left-Central, MC = Mid-Central, RC = Right-Central, LP = Left-Posterior, MP = Mid-Posterior, RP = Right-Posterior.

Discussion. Previously, research has indicated that higher performing participants would have higher baseline power in the alpha and theta frequencies (Klimesch, 1997 & 1999; Klimesch, Schimke, Ladurner & Pfurtscheller, 1990; Klimesch, Vogt & Doppelmayr, 2000) but that was not the case here. However, theta has not only been used as an indicator of performance, but also of relaxation and attention, similar to the alpha frequency (Laukka, Järvillehto, Alexandrov & Lindqvist, 1995; Niedermeyer, 2005) where higher theta power is positively correlated to relaxation.

Differences between the groups were most profound in the gamma frequency, where the Pass group displayed higher gamma power both in overall gamma power as well as in the Mid-Frontal, Mid-Central, Right-Central and Right-Posterior regions. These differences were in line with those of Linkenkaer-Hansen et al. (2004) as well as those of Martinovic and associates (Martinovic, Gruber & Müller, 2007; Martinovic, Gruber, Hantsch & Müller 2008) who found that performance on object classification tasks was positively correlated with gamma power. Various authors have speculated that gamma activity could be understood as a basic building block of complex neural networks and play a critical role in complex learning (see for example Basar & Karakas, 2006; Basar, 2005; C. Basar-Eroglu et al., 1996; Keil, Muller, Gruber, Wienbruch & Elbert, 2001; Jausovec & Jausovec, 2005; Pulvermuller, Birbaumer, Lutzenberger & Mohr, 1997 and Gruber, Keil & Muller, 2001). Most research on gamma has focused on the induced or task related activity, but the current results indicate a presence of a strong distributed gamma network that could serve to facilitate complex learning. The gamma power differences in the Mid-Frontal region could indicate stronger memory and executive functions. Gamma activity in the Right-Posterior region has been shown to correlate with classification tasks (see Martinovic, Gruber & Müller, 2007; Martinovic, Gruber, Hantsch & Müller 2008) and stronger baseline activity in that region

might be indicative of a brain more adept at learning complex tasks such as the equivalence test.

Although an effect in the alpha range might have been expected given previous research results (see for example Klimesch, 1996; 1997; 1999; Klimesch, Schimke, Ladurner & Pfurtscheller, 1997) the lack of alpha effects in the current study was not surprising. No effects had been found in Studies 1, 2 and 3, which indicated that alpha activity is not linked in any significant way to Equivalence responding (although see Roche et al. 2004 for a contrary view). The absence of alpha effects in the current study might be due to the different EEG analysis methods used. For examples Klimesch split the alpha frequency into high and low alpha and has shown that in some cases the two frequency ranges act in opposite ways during cognitive tasks (see also Jausovec & Jausovec, 2000 and Angelakis, Lubar & Stathopoulou, 2004). Different analytic methods, such as the individual alpha frequency, wavelet transformations or hemispheric asymmetry could reveal that alpha activity is related to performance. However, the fact that effects were reliably predicted in other frequencies, such as delta and gamma, undermines the assumption that a different analysis might be to blame for this lack of alpha effect.

When comparing the effects of the different stimulus types on brain responses, most differences were found in the Mid-Posterior region. This finding is not surprising, given that activity in the posterior regions is mostly associated with the processing of visual information and the two stimulus types are likely to induce different activities in that area. The two groups displayed different gamma responses during both the ABE and BCE stages. As was predicted, the most pronounced effects were found in the posterior regions, which were in line with previous research (Gruber & Müller, 2005). The largest difference in the gamma frequency was found at the Mid-Posterior region, where the Abstract group had significantly higher gamma power than the Iconic group. This effect could be attributed to two main

factors. One, the increased difficulty and attentional demands of the abstract task compared to the iconic task which would cause greater activity in the occipital visual regions. Or, second, the increased gamma might be increased covert naming behavior, similar to what was observed in the beta frequency. However, the location of the significant differences would favour the former explanation. Schack, Vath, Petsche, Geissler & Moller (2002, see also Sauseng & Klimesch, 2008) have found that in certain short term memory tasks changes in theta and gamma frequencies are correlated. Schack et al. found that during a Sternberg memory task, the amplitude of the gamma and theta frequencies increased in the region around the Fp1 electrode (Left-Frontal area). However, it is worth noting that Schack et al. (2002) used two types of stimuli, random figures and numbers, and found no difference in amplitude between the two stimulus types. Other researchers have also found relations between theta and gamma responses. Hald, Bastiaansen & Hagoort (2006) found that theta and gamma respond in similar way to semantic violations. However, unlike the current results and the ones found by Schack et al, the effects were more distributed throughout the right part of the frontal hemisphere at the F4 and F8 electrodes. Demiralph et al. (2007) found that overall gamma amplitude is related to overall theta amplitude when participants were made to judge familiar and unfamiliar objects as curved or edgy (a test of visual processing). The experiments mentioned above did however not use the FFT method to extract the EEG data and the experimental protocols were markedly different than the conditional discrimination training employed here. Even though the findings in these experiments were replicated in the current study, these procedural differences limit detailed comparison of the two sets of protocols.

Chapter 6: General Discussion

The primary goal of this program of research was to take steps to identify the neural correlates of stimulus equivalence responding and any possible prerequisite neural activity for equivalence responding. The electrophysiological correlates of both conditional discrimination training and equivalence testing were explored using EEG frequencies in the delta, theta, alpha, beta and gamma ranges. At the same time, steps were taken to develop an experimental protocol which was able to both conform to the requirements of the EEG as well as behaviour analytic standards on equivalence research. The first three studies explored electrophysiological activity during baseline, training and testing but only in participants that displayed equivalence. The results point towards the importance of different EEG frequencies (delta and gamma) than previous research by Roche et al. (2004) using spectral analysis which focused on the alpha frequency. Additional analysis focussed on the differences in EEG activity between participants which displayed equivalence and those that did not, as well as the effect of stimulus types on EEG activity. The results indicate a possible role for posterior gamma activity in the formation of equivalence classes and possible interventions on brain activity with the aim of improving equivalence performance should focus on posterior gamma activity.

Behavioural results

The results from Studies 1 through 3 showed that a clear differences between Pass and Fail participants could be seen as early as in the ABT stage. In Study 1 participants that failed to display equivalence needed almost three times as many trials to advance to the next experimental stage than participants that displayed equivalence. This difference between Pass and Fail was also visible in the ABT stage in Experiments 2.1 and 3.1 where participants were exposed to iconic stimuli. Such a comparison was not possible for data from

Experiments 2.2 and 3.2 as only one participant displayed equivalence in each experiment (see Table 33 below). The difference between the Pass and Fail participants was also visible in the BCT stage in Experiment 1.2; however it was reduced from the previous stage. In Experiments 2.1 and 3.1, the participants' performance was more evenly distributed than in the ABT stage.

Table 33

Summary of behavioural results from all Experiments in Studies 2 and 3

Stage	Experiment							
	2.1		2.2		3.1		3.2	
	Pass	Fail	Pass	Fail	Pass	Fail	Pass	Fail
ABT	4	13	0	14	2	13	0	14
ABE	12	5	4	10	11	4	8	6
BCT	8	9	1	13	7	8	1	13
BCE	16	1	8	7	13	2	10	4
AB/BC	15	2	8	7	N/A	N/A	N/A	N/A
CA	9	8	1	13	6	9	1	13
AC	8	9	2	12	6	9	0	14
BA/CB	12	5	1	13	7	8	0	14

The results from Experiments 1.1 and 1.2 indicated that the familiarity of stimuli plays a role in the acquisition of equivalence as the acquisition of equivalence was faster in Experiment 1.1 than in Experiment 1.2. The results from Experiments 1.1 and 1.2 showed that although participants could be trained to display equivalence relations using abstract stimuli, the amount of training needed was substantially more than when using iconic stimuli. This could be the result of previous visual discriminations that have been trained in the presentation of familiar stimuli. For example, iconic and easily nameable stimuli, such as those used in Experiment 1.1, regularly occasion responses and therefore exert a certain amount of stimulus control on participants' behaviour even before experimental manipulation. These results are in line with previous research on stimulus familiarity such as Dickins, Bentall & Smith (1993) and Holth & Arntzen (1998). The abstract stimuli have no

such history of stimulus control, which might increase the response effort. Difficulty can be operationally defined as either a competition between sources of stimulus control or increase in response effort. An example of the former is a Stroop task, where participants are presented with names of colours printed in colours not denoted by the name (e.g. the word “green” in red letters) and participants have to name the colour of the printed colour instead of the name. This task has a longer response time than simply reading the colour and can be explained by two sources of stimulus control. One is the word “green” and the other is the actual colour of the letters (red). Both can occasion verbal responses, but reading has better stimulus control and therefore interrupts the naming of the stimulus (Eysenck and Keane, 2005). Difficulty as an increase in response effort could entail more actions required to execute a response or more response choices. For example, presenting 10 comparison stimuli in an equivalence task instead of three would increase the response effort. The difference in response patterns seen using the abstract and the iconic stimuli might therefore be traced back to the learning history of the participants (Arntzen & Holth, 1997) as they have a history of matching iconic images which is missing with regards to abstract images.

No pattern of delayed emergence of equivalence was found in the first two experiments, even though the protocol was similar to that used by Holth & Arntzen (1998) where the authors reported delayed emergence response patterns in participants exposed to iconic stimuli but not those exposed to abstract stimuli. However, participants in both Experiments 1.1 and 1.2 performed better during the Equivalence test stage than during the Transitivity test stage which was tested later. This improvement in performance could be labelled delayed emergence as both Equivalence and Transitivity are derived responses. However, if so then the pattern found differs from that found by Holth & Arntzen who observed delayed emergence in participants exposed to iconic but not abstract stimuli.

Electrophysiological results

Previous research (Dickins et al, 2001; Barnes-Holmes et al., 2005a & 2005b; Schlund, Hoehn-Saric & Cataldo 2007, Roche et al., 2004) had linked activity in the pre-frontal cortex to equivalence responding and found neural activity during equivalence to be similar to that observed during semantic priming. Additionally, initial research by Roche et al. indicated that the alpha frequency might be correlated to the equivalence responses in the brain, but a small sample size limited the generalisation of those results. Moreover, the localization of neural correlates of equivalence using EEG has not been fruitful, and generalizing results across different analysis methods (from fMRI to EEG) is unreliable due to the differences in both temporal and spatial accuracy. Therefore, focusing the EEG analysis on specific areas of interest based solely on results from fMRI results was not chosen in the current project.

The conditional discrimination training paradigms that have been developed with stimulus control literature to effectively analyse stimulus equivalence include a number of features that make it difficult to unequivocally identify neural correlates of stimulus equivalence. Stimulus equivalence employs rigorous experimental control over participants' responses and reinforcement histories in order to identify how these histories give rise to equivalence. It may seem paradoxical, but the methods used to establish such control can raise issues when one attempts to measure certain neural predictors of that behaviour. For instance, participants in equivalence experiments are not typically exposed to the same number of trials during training. Variation in the amount of training arises because participants are required to satisfy a mastery criterion before training ends. This is to ensure that the trained conditional discriminations are reliably demonstrated by all participants prior to testing for emergent or derived conditional discriminations (i.e., symmetry, transitivity and equivalence). This variation in the amount of training received by participants can be

problematic for EEG research. For example, if a researcher wants to investigate the alpha frequency correlates of A-B conditional discriminations it is important that participants' receive equal training because alpha is sensitive to fatigue. More importantly, if pre equivalence EEG activity is related to equivalence responding, then those possibly important relationships are missed by not including the pre testing stages in the analysis.

Given the different experimental histories of participants in equivalence paradigms and potential effects of these histories on EEG, one approach to analyse the neurological correlates of equivalence has been to measure EEG only during equivalence testing (e.g., Dickins, et al, 2001; Schlund et al., 2007). This approach has indeed worked in these studies in so far as it has identified certain regions of interest such as the DLPFC. However, by doing this an important part of the complete picture was overlooked as the neurological correlates of training have been missing. That neurological activity might be correlated with later equivalence responding and thus deserves attention equal to the activity during equivalence responding. The procedural limitations mentioned above were partially addressed in this project. As an alternative to the approach taken in previous studies, Experiments 2.1 throughout 3.2 standardised exposure to training across participants. In this way, it was possible to control for the fatigue and training effects in the EEG data by exposing all participants to the same number of trials during training. The protocols used in Studies 2 and 3 were effective in differentiating between well and poorly performing participants, detected differences in EEG activity throughout the experimental task and at the same time had enough experimental trials to satisfy the criteria for useful EEG data.

In Experiments 1.1 and 1.2, baseline effects were found in the delta and alpha frequencies but no effects in the theta frequency. The lack of stage effects in the first two experiments could be attributed to several factors. First, each stage of the experiment had relatively few trials as participants were required to respond correctly in 19 out of every 20

trials during training and only in 11 out of 12 during testing blocks. Second, the amount of training needed differed between participants which introduced a variable into the data which could not be reliably accounted for in the EEG analysis. However, this method of training to a criterion is widely used in the stimulus equivalence literature and was an important first step in the study at hand. Third, the total length of the protocol varied across participants, introducing another time variable into the EEG measurements and possibly decreasing the quality of the EEG signal.

Despite the above-mentioned limitations of the first experimental protocol, a number of important factors could be inferred by the results. The FFT analysis reliably identified a difference we were expecting to find (the baseline effect), even with few experimental trials. The baseline effects indicated that the equivalence procedure does in fact significantly impact the amplitude of the EEG frequencies in the delta and alpha frequencies and to some extent in the theta frequency. These experiments were therefore useful as an integrity check for the effectiveness of a stimulus equivalence task to impact the EEG recordings. However, sensitive differences between the task stages could not be identified using this paradigm.

As in Experiments 1.1 and 1.2, delta power in Experiments 2.1 and 3.1 was found to be highest in the posterior and central regions during the task stages and additionally was found to be significantly higher during Extinction than during other measured task stages (see Table 34 below for summary of EEG results from Studies 1, 2 and 3).

Table 34

Summary of EEG results from all Experiments in Studies 1, 2 and 3

Frequency	Experiment			
	1.1	1.2	2.1	3.1
Delta	*Baseline < Train, Test (MF, MC, RC, LP, MP, RP)	*Baseline < Train, (MF, MC, RC, LP, MP, RP); *Baseline < Test (LP, MP, RP)	*Baseline < Train (LF, RF, LC, MC, RC, LP, MP, RP); *Baseline < Ext (LF, RF, LC, MC, RC, MP, RP); *Baseline < Eq (RF, LC, MC, RC, LP, MP, RP); *Ext > Train (LP); *Ext > Eq (RF, RC, MP)	*Baseline < Train (LF, MF, RF, LC, RC, LP, MP, RP); *Baseline < Ext (LF, MF, RF, LC, RC, LP, MP, RP); *Baseline < Eq (LF, MF, RF, LC, RC, LP, MP, RP)
Theta	No significant results	No significant results	*Baseline < Train (MF, RF, LC, RC, LP, MP, RP); *Baseline < Ext (MF, LC, RC, LP, MP, RP); *Baseline < Eq (MF, RF, LC, RC, LP, MP, RP); *Ext < Train (LP) *Ext < Eq (RF, MP)	*Baseline < Train (RC); *Baseline < Ext (RC) *Baseline < Eq (RC)
Alpha	*Baseline > Train, Test (All regions)	Baseline > Train, Test (All regions)	*Baseline > All stages (All regions)	*Baseline > All stages, all regions; *Ext > Train (RP)
Beta	--	--	*Baseline > All stages, (All regions)	*Baseline > Train (LF, MP); *Baseline > Ext (MP); *Baseline > Eq (LF, MP)
Gamma	--	--	*Baseline > Train (MC, MP); *Baseline > Ext (MC, MP); *Baseline > Eq (MC, MP); *Ext < Eq (MC)	No significant results

Note: No analysis was conducted in the beta and gamma ranges in Experiments 1.1 and 1.2

Delta. In Experiment 2.1, the greatest delta power was observed during Extinction in participants that displayed equivalence. One potential explanation of this is that for the participants that displayed equivalence, the most difficult stage in the experiment was the Extinction stage but not the test for Equivalence. Previous research has shown that Delta power varies with task difficulty (Brookings, Wilson & Swain, 1996). Another possibility is that the increase in delta activity is related, not to the perceived difficulty of the task, but to the contingencies of reinforcement. Specifically, the process of extinction might have given rise to greater delta power. The extinction stages during training presented the very same trials as the preceding training stages, but the previously reinforced responses were not reinforced. It is well established that both behavioural variation and frequency increase during extinction (Killeen & Hall, 2001; Pierce & Cheney, 2004; Sidman, 1960). Some authors have speculated that for any behavioural activity, there should be a corresponding neural activity (see for example Donahoe, 1984; Donahoe, Burgos & Palmer, 1993; Donahoe & Palmer, 2004; Palmer & Donahoe, 1992) or that activity patterns seen at the behavioural level can be thought of as analogous to activity patterns at other levels of analysis (genetic, physiological or cultural). The increase in delta amplitude in the current project could be interpreted as a neural correlate of extinction. It is worth noting, however, that accuracy did not decrease in the Pass groups during extinction.

Theta. Aside from changes between Baseline and task stages, the only noteworthy results in the theta range were found in the Right-Frontal and Mid- and Left-Posterior regions where Theta power during extinction was lower than during other task stages (see Table 42 above). This could indicate that even though theta responses are not isolated to any specific behaviour needed for display of equivalence, theta activity in these regions does play a role in the learning process. Theta activity in the Mid – and Frontal regions has been associated with short term and working memory functions (Sauseng et al., 2003, Sauseng & Klimesch, 2008)

and the equivalence training includes elements of working memory functions, it is possible that different analysis methods might uncover task related activity at those locations. To ascertain this, more detailed analysis is needed on the theta response at this location during all stages of the equivalence task.

Alpha. The lack of stage effects in the alpha range found in the first experiments was replicated in the latter experiments; alpha activity did not show any significant changes between the three task stages and no region showed exceptional alpha activity. Alpha has been used as an indicator of attention and fatigue (see for example Klimesch, 1996), as well as daydreaming (Rowan & Tolunsky, 2003) and is a reliable inverse indicator of attention. These results would indicate that the experimental setting did not induce fatigue in the participants and that the EEG data was reliable and not due to insensitive equipment or inadequate analysis. However, it is unlikely that the alpha frequency has any functional correlates to equivalence responding.

Beta. In Experiments 2.1 and 3.1 beta and gamma frequencies were added to the analysis. Only a baseline effect was detected in Experiment 2.1, however, beta power increased in the Left-Frontal and Mid-Posterior regions, which could be attributed to the participants verbalizing (rehearsing) the pairs presented to them in order to correctly respond to them later. Miller (2007) observed a similar effect in the left hemisphere, but some researchers (see Hwang et al., 2005) have observed this effect to occur bilaterally and in the Mid-Frontal region. The decrease in beta power in posterior regions from Baseline to task was also expected, as this posterior drop in beta power has been associated with learning during operant conditioning (see Papousek & Schuter, 2004). However, the changes reported by Hwang et al. and Papousek & Schuter were event related and might therefore not be accurately replicated using the FFT method employed in the current project.

Gamma. The results in the gamma frequency were somewhat different in experiments 2.1 and 3.1. This lack of strong coherent results in the gamma frequency might be attributed to a number of factors. The published research on gamma frequency correlates has focused on event related analysis of the gamma response, often using simple tasks with a go/no-go or yes/no response requirement. The task used in this study was substantially more complex and might therefore have induced activity in a wider range of neural networks than the simpler tasks used in the previous literature. Another possible reason for the discrepancy is that the gamma frequency extracted here was only in the 30-40 Hz range but a broader frequency range could be needed to capture gamma responses in this task. However, using a broader frequency band might also mask any possible effects as the amplitude of gamma drops substantially after 40 Hz (see Herrmann, 2003).

Additional analysis

In the baseline comparisons between the Pass and Fail groups, differences were only found in the gamma frequency. Although no effects were found in the gamma range during the task in participants in the Pass group, significant and widespread differences were found between the groups during the eyes open baseline. The most pronounced differences were found in the Mid-Frontal region, but theta activity there, both during baseline and tasks, has been associated with task performance. Given the close association of theta and gamma activity (Herrmann, Fründ & Lenz, 2010), and if theta activity in that region is active during task performance, this gamma activity might serve as a catalyst for theta activity (Schack et al., 2002). As mentioned earlier, gamma activity has been recorded in the Right-Posterior region during transitive reasoning tasks but was not found during task performance here. The results here, on the other hand, reinforce the notion that the Right-Posterior region might play a role in equivalence responding. One possible reason for the lack of significant differences

in gamma during the task stages is that the measure used here for learning performance does not allow for a grading slope and participants either passed or failed each stage. Although improbable, it is possible that a participant that responded 66% correct had simply chosen, by chance, the correct stimulus pairs. Subsequently, if gamma is related to equivalence responding, that participants' gamma activity should not be any different than a participant that is simply guessing which stimuli are related in the conditional discriminations or in the equivalence tests. This would render any grading of the current behavioural results invalid. Although differences were found between the groups during the baseline period, in the gamma frequency, it is unclear if those differences represent a trait or state variable. Although it is possible that the differences are indicative of stable individual differences (or a trait), these differences might also be due to differences in participants state at the time of testing. To ascertain if this baseline difference is a stable 'trait' or a function of a variable physiological state, more extensive research will have to be conducted.

As was mentioned earlier, Jausovec & Jausovec (2005) found differences in parietal gamma activity that correlated with scores on verbal intelligence. The differences detected in gamma amplitude here could lend further support to the results of Jausovec & Jausovec and also to the link between intelligence and equivalence. However, this must be done with caution as the differences found in this study were found during baseline, but Jausovec & Jausovec detected their differences during task activity. A more detailed analysis of the EEG data is needed and direct comparisons must be made using a test of verbal intelligence to further answer the question if equivalence, verbal intelligence and gamma amplitude are linked.

Given that activity in the posterior regions has been associated with the processing of visual information, and that the two stimulus types (abstract and iconic) are likely to induce different activities in that area, it is not surprising that the most pronounced differences

between the Abstract and Iconic groups were found in those regions. In the Mid-Posterior region, differences were again found in the gamma frequency during the BCE stage.

The effects found in the Mid-Posterior region in the gamma frequency might be attributed to the increased difficulty and attentional demands of the abstract stimuli compared to the iconic stimuli. This increased difficulty would then induce more frequent or elaborate covert naming behaviour which would further increase the gamma responses. As previously mentioned, the simultaneous occurrence of theta and gamma responses in the frontal regions has been reported in the literature during complex tasks. There is a possibility that the effect found in the gamma frequency is a part of a larger network of responses which is activated by the conditional discrimination training. However, as not all the participants that finished the AB and BC training displayed equivalence, these networks are perhaps necessary, but not sufficient for the display of equivalence.

Limitations and suggestions for future research

Despite the conclusions and discoveries from the current research project, several limitations must be addressed. Although correlations were found between gamma activity and performance on the task, the current research cannot ascertain anything about any possible causal effects that the gamma wave might have on performance on stimulus equivalence. Already, some authors have claimed that by influencing EEG frequencies one can improve performance on a wide array of cognitive tasks. This can be done either directly with methods such as transcranial magnetic stimulation (TMS, Klimesch, Sauseng and Gerloff, 2003; Marshall, Helgadóttir, Mölle and Born, 2006), or transcranial direct current stimulation (tDCS, Marshall, Mölle, Hallschmid and Born, 2004; Sparing, Dafotakis, Meister, Thirugnanasambandam and Fink, 2008) or indirectly using methods such as neurofeedback (Lusted and Knapp, 1996). The reasons for the exclusion of a neurological intervention are

twofold. First, compared to the relatively simple EEG equipment, the equipment needed for both neurofeedback and stimulation is expensive and would have required extensive training to master. This was not feasible due to time and financial limitations. Second, it would not have been clear exactly which frequencies to focus the intervention on nor at which regions the interventions should have focused in order to increase performance on the stimulus equivalence task. As explained earlier, very little research has been conducted on the electrophysiological activity of stimulus equivalence, and therefore the likelihood of an intervention being unsuccessful were quite high. However, the current results would give future researchers some indication as to where to focus their interventions (posterior gamma).

Another limitation is the number of participants that displayed equivalence in the Abstract conditions. This made comparing the Abstract and Iconic groups EEG activity during equivalence responding which would have been beneficial in order to ascertain if there is a certain type of neural activity associated with equivalence responding regardless of long term learning histories of equivalence behaviour.

Although the FFT analysis did display advantages over previously used ERP measures in some regard, it should be noted that the FFT does have less temporal accuracy than traditional ERPs. The main advantage that FFT analysis has over ERP is that it allows for a greater accuracy in frequency measures. Another event related analysis is the wavelet analysis which enables analysis on the time, frequency and amplitude scales simultaneously (Herrmann, Grigutsch & Busch, 2005). The wavelet analysis does, on the other hand, require a certain trade off between spectral and temporal accuracy. That is, the more accurate the frequency scale, the more coarse the spectral scale and vice versa. Using the wavelet analysis would then become a delicate balancing act of picking the right ratio of frequency/temporal accuracy in the analysis in addition to developing an experimental protocol which meets standards used in both behavioural and physiological experiments.

To further explore the extinction effect, the reinforcement schedule should be systematically changed or two different extinction schedules compared. If delta activity fluctuates in a way that is compatible with the differences in the extinction schedules, then the delta activity can reliably be linked with extinction. Reinforcement can be gradually withdrawn and then re-introduced in a return to baseline format to explore the relationship between delta (and other frequencies) and the reinforcement schedule. Alternatively, the amplitude of different frequencies can also be used as a measure of response strength. Killeen & Hall (2001) citing Skinner (1938) define response strength as “the state of the reflex with respect to all its static properties at once” (p. 111). According to Killeen & Hall, any response is made up of various properties such as force, rate, persistence, probability, topography etc. and if any of these properties co-vary it is assumed that they constitute a measure of the response strength. Thus in order to identify response strength more than one dependent variable must be measured. For example, if reaction times were included in the analysis, a possibly valid and coherent measure of response strength could be obtained using the current protocol. Another measure of response strength could also be obtained by varying the difficulty of the task. Hinton, Dymond, Von Hecker & Evans (2010) demonstrated that brain activation varied according to the number of members in a class using a more-than/less-than relational testing procedure.

Hinton et al. used a novel five term relational reasoning paradigm during fMRI scanning. Prior to scanning, participants were trained in a series of more-than ($E > D > C > B > A$) and less-than ($A > B > C > D > E$) relations. Imaging was conducted during testing of adjacent ($A < B$, $B < C$, $C < D$, $B > A$, $C > B$, $D > C$), one-step ($A < C$, $B < D$, $C < E$, $C > A$, $D > B$ and $E > C$) and two step ($A < D$, $B < E$, $D > A$ and $E > B$) tasks. Reaction times and brain activation co-varied according to number of steps in the testing protocol. A similar measure might be possible using a slight variation of the protocols used in Experiments 2.1 through 3.2, by adding a

fourth member to each equivalence class and testing BA, CB and DC Symmetry relations; A-C, A-D and B-D Transitivity relations and C-A, D-A and D-B Equivalence relations. Using that method, three measures of strength would be possible: electrophysiological activity, response time and accuracy.

One of the most important things to keep in mind in future research is EEG effects that are not due to the phenomena of interest. The phenomena of interest are for example different types of derived relations (symmetry, transitivity, equivalence etc.), different reinforcement schedules and types of stimuli used in the experiment as well as individual variables such as intelligence. However, when analysing the EEG data, other factors might interfere with or contaminate the results. One such factor, for example, is the trial length chosen for analysis. For example, the delta wave has a frequency of .5-4 Hz which means that a .5 Hz frequency takes 2 seconds to complete and therefore all experimental paradigms of interest must take this into account. That is, if the period of interest is the time between the presentations of a sample stimulus until the presentation of a comparison stimulus, the ISI must be at least 2 seconds for any possible induced delta wave to finish its cycle. Such minute changes in experimental protocol are usually not relevant to behaviour analysts but can be of significant importance to the experimental results.

Conclusion

This thesis explored the brain activity during training and testing of stimulus equivalence, specifically the brain activity that differentiates participants that displayed equivalence from that do not and explored physiological activity at various stages of the equivalence task. The results indicated that baseline gamma activity can be used as a predictor for performance on simple equivalence tasks. The findings of baseline gamma differences between participants that successfully displayed equivalence and those that did

not could potentially be used to tailor training methods to different participants. The activity in the gamma frequency also indicate that simple equivalence employs similar brain processes as categorization, as opposed to the alpha frequency which was previously linked to equivalence and language behaviour. These results, although somewhat different from the original predicted results, did fulfil the goals of the project which was to identify biological variables that could be used to predict performance on equivalence tasks and lay the foundation for an eventual intervention of those variables to influence performance on equivalence tasks. At the beginning of this project, delta, theta and alpha frequencies were predicted to play the most prominent role in equivalence behaviour. However, it seems that gamma might be more important than any of the other three frequencies.

A clear difference in response patterns was found between participants exposed to iconic (experiments 1.1, 2.1 and 3.1) and abstract stimuli (experiments 1.2, 2.2 and 3.2). Participants in the iconic experiments displayed faster acquisition than participants in the abstract experiments as was evident in experiments 1.1 and 1.2. Iconic stimuli also facilitated learning of equivalence responses as only two out of 28 participants in experiments 2.2 and 3.2 displayed equivalence while 12 out of 31 participants in experiments 2.1 and 3.1 displayed equivalence. This is similar to effects previously described by Arntzen (2004, 2006); Arntzen & Holth (1997, 2000); Dickins, Bentall & Smith (1993) and Holth & Arntzen (1998). However, these clear behavioural differences were not mirrored in differences in neurological activity. Only posterior gamma activity during Extinction was found to be substantially different between the two groups. It is possible that other EEG analysis methods with more spectral accuracy would be able to detect differences in the neural responses to the two stimulus types.

Contrary to results found by Dickins et al. (2001) and Schlund et al. (2007) no specific activation was found in language areas (which would roughly correspond to the

Right – and Left – Central regions used for analysis here). Additionally, the one published study on spectral power during equivalence (Roche et al. 2004) identified the alpha frequency as a possible catalyst for equivalence. Those results were not replicated here as the only noticeable effect found in the alpha frequency was the change found between Baseline and task stages. However, activation was found in regions and frequency previously associated with categorization (see for example Herrmann, 2003 and Herrmann, Fründ, & Lenz, 2010). This lends further support to the idea put forth by Galizio, Stewart & Pilgrim (2001) that equivalence can serve as a behavioural model for artificial categorization.

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Appendix 1

Consent form

In giving my consent to participate in this research project, I acknowledge that I am fully aware of the following:

Jón G. Sigurjónsson, a postgraduate student of psychology in the National University of Ireland, Galway, is conducting this research project. Jón G. Sigurjónsson will take it upon himself to ensure that all ethical guidelines are adhered to, where participants and their data are involved.

The researcher has provided me with general information on the study. I understand that I will be required to carry out a computer-based task, during which time my electrophysiological activity will be monitored. I also understand that I cannot partake in this experiment if I have had major head trauma, am taking psychotropic medication or have been diagnosed with epilepsy.

All data from the research project will be kept confidential and will only be used in a research context. The data will be collected and analyzed so as to be included in the researcher's doctoral thesis. At no stage will any of the participants from whom data is collected be identified by name.

After participation has been completed, the researcher will address any queries or concerns that I may have. I will be debriefed in full when the final report has been drafted.

I am aware that I am free to withdraw my participation from this study at any time and can deny the use of my data in any analysis, if I so wish. I am also aware that I do not have to partake in this research and am doing so of my own free will.

Signed

Date:

Participant:

Student ID (if applicable):

Researcher:

Appendix 2 Edinburgh Handedness Inventory

Please indicate your preferences in the use of hands in the following activities *by putting a check in the appropriate column*. Where the preference is so strong that you would never try to use the other hand, unless absolutely forced to, *put 2 checks*. If in any case you are really indifferent, *put a check in both columns*.

Some of the activities listed below require the use of both hands. In these cases, the part of the task, or object, for which hand preference is wanted is indicated in parentheses.

Please try and answer all of the questions, and only leave a blank if you have no experience at all with the object or task.

	Left	Right
1. Writing	<input type="checkbox"/>	<input type="checkbox"/>
2. Drawing	<input type="checkbox"/>	<input type="checkbox"/>
3. Throwing	<input type="checkbox"/>	<input type="checkbox"/>
4. Scissors	<input type="checkbox"/>	<input type="checkbox"/>
5. Toothbrush	<input type="checkbox"/>	<input type="checkbox"/>
6. Knife (without fork)	<input type="checkbox"/>	<input type="checkbox"/>
7. Spoon	<input type="checkbox"/>	<input type="checkbox"/>
8. Broom (upper hand)	<input type="checkbox"/>	<input type="checkbox"/>
9. Striking Match (match)	<input type="checkbox"/>	<input type="checkbox"/>
10. Opening box (lid)	<input type="checkbox"/>	<input type="checkbox"/>
<u>TOTAL(count checks in both columns)</u>	<input type="text"/>	<input type="text"/>

Difference	Cumulative TOTAL	Result
<input type="text"/>	<input type="text"/>	<input type="text"/>

Scoring:

Add up the number of checks in the “Left” and “Right” columns and enter in the “TOTAL” row for each column. Add the left total and the right total and enter in the “Cumulative TOTAL” cell. Subtract the left total from the right total and enter in the “Difference” cell. Divide the “Difference” cell by the “Cumulative TOTAL” cell (round to 2 digits if necessary) and multiply by 100; enter the result in the “Result” cell.

Interpretation (based on Result):

- below -40 = left-handed
- between -40 and +40 = ambidextrous
- above +40 = right-handed