The Role of Attention in Learned Contingency Tasks

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Abstract

Over the last forty years, experimental support for different models of associative learning has come from a range of phenomena. Support for the Rescorla-Wagner (1972) model comes from blocking and overshadowing experiments; however, this model is unable to explain the findings of latent inhibition experiments. The Mackintosh (1975) model, on the other hand, is able to accommodate the findings from blocking, overshadowing and latent inhibition experiments, as well as discrimination learning, relative validity, learned irrelevance, intra-/extra-dimensional shift (IDS/EDS) and learned predictiveness experiments. The model proposed by Pearce and Hall (1980) is also able to explain the findings of blocking, overshadowing and latent inhibition experiments, but in addition to this it is also able to accommodate the effects of partial reinforcement and negative transfer. In an attempt to unify the theories into a single model that is able to explain all the aforementioned phenomena, Le Pelley (2004) proposed a hybrid model of associative learning, but it was not easily able to incorporate the effects of learned value. Alternatively, Esber and Haselgrove (2011) proposed a model that reconciles the influence of predictiveness and uncertainty into a single mechanism for attentional allocation, and this model was better able to explain the experimental findings of learned value.

Theories of associative learning claim that a cue's predictive validity determines the amount of attention it attracts and to what extent it is subsequently learned about (e.g. Mackintosh, 1975; Pearce & Hall, 1980). In

Chapter 2, using eye-tracking methodology during a learned predictiveness task, several measures of overt attention were recorded and compared on trials where the predictive contingency was certain or less certain. Findings revealed that, at a within-trial level, good predictors of an outcome attracted more attention compared to irrelevant cues. Although, at a between-trial level, uncertain trials attracted more attention compared to certain trials. These findings provide support for the conflicting attentional modulation predictions made by the Mackintosh (1975) and Pearce-Hall (1980) models. Consequently, these findings can only be fully explained by appealing to a model of associative learning that incorporates both the principles of predictiveness and uncertainty (e.g. Le Pelley, 2004; Esber & Haselgrove, 2011).

Prior to eye-tracking becoming more widely available as a measure of overt visual attention, stimulus associability was used as an indirect measure of attention since it is assumed that the speed at which a stimulus is learned about reflects the amount of attention it attracts. This is demonstrated in the IDS/EDS task which consistently finds that IDS are easier than EDS because in the IDS condition the higher associability of the predictive dimension in Stage 1 facilitates learning when generalised into Stage 2. Until now, eye gaze during an IDS/EDS task has not been investigated to determine whether the effect results from a shift in overt attention from Stage 1 into Stage 2. Chapter 3 revealed that participants acquired an attentional bias towards predictive cues in Stage 1 which transferred into Stage 2; however, in the EDS condition this bias was maintained only very briefly.

Eye-tracking during learned predictiveness tasks using adult participants has revealed that cues which are good predictors of an outcome attract more

overt visual attention than cues which are irrelevant. However, thus far, little research has investigated whether good predictors of reinforcement and non-reinforcement show a comparable effect. Moreover, it is currently unclear whether children and non-human animals demonstrate the learned predictiveness effect. Chapter 4 employed the same design and stimuli to examine eye gaze towards cues during a simple learned predictiveness task (AX+, AY+, BX-, BY-) in adults, children and an orangutan. Results revealed that all participants demonstrated the learned predictiveness effect, directing more attention towards cues that were good predictors of the outcome compared with cues that were irrelevant. However, for adult humans this effect was only present on reinforced trials and questionnaire data suggested they had only learned about one of the predictive contingencies.

Contemporary discussions of associative learning have emphasised the importance of a cue's predictive relevance in determining learned variations in attention. However, most theoretical accounts of the effect do not capture the notion of prediction – only associative strength, or relative associative strength (e.g. Mackintosh, 1975). In Chapter 5, letters were established as congruent or incongruent cues of other letters presented simultaneously or serially with a target cue. Results revealed no difference in the amount of attention directed towards congruent and incongruent cues if stimuli were presented simultaneously or serially when participants were required to respond to the identity of the target cue. However, an attentional bias towards congruent cues compared to incongruent cues was found when cues were presented serially, if participants were permitted to predict the identity of the target before its onset.

Summary of experiments

In Chapter 2, Experiment 1 explored whether different measures of attention, recorded by eye-tracking, correlate with the predictive validity of a cue - the learned predictiveness effect. Results revealed that dwell time, proportion of dwell time, fixation count and proportion of fixation count, displayed the learned predictiveness effect and were highly correlated with each other; whilst latency to first fixation did not exhibit the learned predictiveness effect and was not well correlated with any of the other measures of attention. Experiment 2 part-replicated the experimental design used by Hogarth, Dickinson, Austin, Brown and Duka (2008) which almost uniquely found support for the Pearce-Hall (1980) model in humans. Our results did not directly replicate their findings but did find that certain and uncertain predictors of reinforcement attracted more attention than certain predictors of non-reinforcement. Although, within reinforced and non-reinforced trials, predictive cues attracted more attention compared to irrelevant cues. These observations offer support for the Pearce-Hall (1980) and Mackintosh (1975) models of associative learning. Experiment 3 explored the overt visual attentional distribution in cases of high and low certainty. Similarly to Beesley, Nguyen, Pearson and Le Pelley (2015), the results demonstrated that at a between-trial-level, more attention was directed during uncertain trials compared to certain trials, but at a within-trial-level no difference was observed between the amount of attention directed towards predictive and irrelevant cues.

In Chapter 3, Experiment 4 investigated whether the bias in associability thought to underpin the IDS/EDS effect is accompanied by a bias in visual

attention. Findings revealed that the IDS/EDS effect is caused by generalising the attentional bias established in Stage 1 into Stage 2, but that in the EDS condition this bias was only maintained for the for the first two trials. Experiment 5 rectified a confound in the experimental design used by Beesley et al. (2015), and found that participants looked more towards predictive cues than irrelevant cues in Stage 1 and 2 during conditions where the predictive contingencies were 100%, regardless of whether these contingencies were congruent or incongruent between Stage 1 and 2. However, during the condition in which the predictive contingency was 100% but this continency was switched between Stages 1 and 2, this pattern of results was reversed for the first two trials in Stage 2, suggesting that participants generalised what they had learned in Stage 1. No difference was found in the amount of attention that predictive and irrelevant cues attracted during conditions where the predictive contingencies were 75%, regardless of whether the predictive contingences were switched between Stages 1 and 2.

Chapter 4, established a simple learned predictiveness task that could be used with both human and non-human animals. Experiment 6 investigated whether an orangutan, which had been trained to wear a head-mounted eye-tracker, exhibited an attentional bias during a learned predictiveness task as predicted by the Mackintosh (1975) model and human literature. The orangutan directed more attention towards predictive cues compared to irrelevant cues, specifically towards cues that predicted the omission of reinforcement. Experiment 7 employed the same paradigm with children and found that they also demonstrated the learned predictiveness effect. In addition, cues that were good predictors of non-reinforcement enjoyed the same enhanced attention

received by cues that were good predictors of reinforcement. Experiment 8 tested adult participants and found that they directed more attention towards cues that were predictive of the occurrence of reinforcement. However, questionnaire data obtained after the experiment revealed that participants had only learned the reinforced predictive contingency.

In Chapter 5, Experiment 9 tested the assumption that mere association is sufficient to bias attentional capture. By presenting a correlated (always presented with the target stimulus), uncorrelated and target stimuli simultaneously it was revealed that simultaneous presentation is not sufficient to produce an attentional bias towards a correlated stimulus. Experiment 10 replicated the experimental design of Experiment 9, however, it also included trials in which correlated and uncorrelated stimuli were presented serially with target stimuli. The serial condition was also divided into two groups: Group Target who just responded to the identity of the target stimulus as fast as they could, and Group Cue who we encouraged to 'predict' the identity of the subsequently presented target stimulus. Like previous experiments, Experiment 10 found that close temporal contiguity was not sufficient to produce an attentional bias, in addition the cue also needed to be predictive of the outcome. Finally, Experiment 11 sought to establish whether the lack of attentional bias towards correlated stimuli, also resulted in no change to their associability. Experiment 11 was divided into two groups, one that received stimuli presented simultaneously in Stage 1, and one that received stimuli presented serially in Stage 1. In Stage 2, both groups received stimuli presented serially; however, both groups were further divided so that for one group the same stimuli that were correlated in Stage 1 were also correlated in Stage 2, but for the other group

they were not. Results suggested that associability had biased during Stage 1 for all groups since participants' accuracy was above chance from the outset of Stage 2.

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Chapter 1:

General introduction

Attention is a selection mechanism which serves as a gateway between the mass of potential information available (externally & internally), and the smaller subset that is subsequently processed. Since cognitive processing capacity is limited (Kahneman, 1973), one role of attention is to select important features in our environment for further learning. Attentional theories of associative learning (e.g. Mackintosh, 1975; Pearce & Hall, 1980) argue that it is a cue's predictive validity which influences how much attention it attracts, and therefore the extent to which the cue is learned about.

Support for this contention comes from phenomena such as the intra-/extra-dimensional shift (IDS/EDS) effect (George & Pearce, 1999; Mackintosh & Little, 1969; Oswald et al., 2001; Shepp & Eimas, 1964; Shepp & Schrier, 1969), the learned predictiveness effect (Beesley et al. 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley, Beesley, & Griffiths, 2011; Le Pelley & McLaren, 2003; Le Pelley, Mitchell, & Johnson, 2013; Le Pelley, Suret, & Beesley, 2009; Le Pelley , Turnbull, Reimers, & Knipe, 2010; Lochmann & Wills, 2003; Mitchell, Griffiths, Seetoo, & Lovibond, 2012), and learned irrelevance (Mackintosh, 1973; Myers, Oliver, Warren & Gluck, 2000; Orosz, Feldon, Gal, Simon & Cattapan-Ludewig, 2007; Orosz, Feldom, Gal, Simon & Cattapan-Ludewig, 2008; Orosz et al., 2011). Subsequently, attentional theories of associative learning have begun to surpass more traditional non-attentional theories of learning (i.e. Miller & Matzel, 1988; Pearce, 1994; Rescorla & Wagner, 1972) which do not grant learned variations in attention to cues.

Attentional models of associative learning (see: Esber & Haselgrove, 2011; Kruschke, 2001; Le Pelley, 2004; Mackintosh, 1975; Pearce & Hall, 1980; Pearce & Mackintosh, 2010) propose that the amount of attention directed

towards a cue is influenced by prior experience of the relationship between the cue and outcome; although, the mechanism by which that is achieved remains the subject of contention. For example, the model proposed by Mackintosh (1975) claims that attention is driven by cue relevance. Therefore, more attention will be directed towards cues that are the best available predictor of a motivationally significant outcome. However, the Pearce-Hall (1980) model claims that attention is driven by predictive accuracy. That is, cues that are followed by surprising outcomes will attract more attention compared to those that correctly predicted the outcome.

The aim of this introductory chapter is to introduce phenomena that provide support for various models of associative learning. In the remaining chapters we will test predictions made by the models outlined to determine which is best able to explain the data, and shed light on the role of overt selective attention within associative learning.

1.1 Rescorla and Wagner (1972)

Arguably the most influential model of associative learning was produced by a collaboration between Rescorla and Wagner (1972), and forms the basis of many contemporary attentional models of associative learning. The aim of the model was to describe the circumstances under which a basic form of learning, Pavlovian conditioning, takes place. According to Rescorla and Wagner, paired presentations of a cue (e.g. a conditioned stimulus, CS) and an outcome (e.g. an unconditioned stimulus, US) will permit the change in the strength of the connection, or association between their internal representations. The degree of this change is described in Equation 1.1.

$$\Delta V = \alpha\beta(\lambda - \sum V) \qquad \textbf{Equation 1.1}$$

According to Equation 1.1, the change in the associative strength (ΔV) between a cue and an outcome is primarily determined by the amount of processing that is afforded to the US, which itself is determined by the discrepancy between the maximum amount of conditioning supported by the outcome (λ) and the total associative strength of all cues present ($\sum V$). The magnitude of this change is influenced by two learning-rate parameters which have fixed values between 0 and 1 based on the unconditioned salience of the cue (α) and the outcome (β).

The success of the Rescorla-Wagner (1972) model has been in part due to the fact that it is able to provide explanations for and make successful predictions about the effect of presenting several cues simultaneously with an

outcome. In particular, the Rescorla-Wagner model is able to provide explanations for phenomena that are pivotal in associative learning which had been previously difficult to explain with extant models of learning (e.g. Bush & Mosteller, 1955): overshadowing and blocking.

Overshadowing was first reported by Pavlov (1927; see also: Chamizo, Aznar-Casanova & Artigas, 2003; Denton & Kruschke, 2006; Dwyer, Haselgrove & Jones, 2011; Holland, 1999; Mackintosh, 1971; 1976; Tennant & Bitterman, 1975; Waldmann, 2001). It occurs when two neutral cues (cues A and B) are conditioned in compound. However, when the elements are tested by themselves, one element (cue B) elicits a stronger response than the other because it has a higher salience. During Pavlov's experiment, thermal and tactile stimuli were presented simultaneously (the CSs) and followed by the consumption of dilute acid (the US). The results revealed a CR (salivation) when the compound cue was presented, but not when the tactile stimulus was presented alone. It is said that learning about the tactile stimulus was overshadowed by the thermal stimulus.

The Rescorla-Wagner (1972) model is able to explain overshadowing by assigning an initially neutral value for a cue's elements ($V_A = 0$, $V_B = 0$, $V_A + V_B = 0$). However, the salience of one of the cues is set higher than the other (e.g. $\alpha A = .7$ & $\alpha B = .3$) and therefore cue A will acquire more associative strength compared to cue B on each conditioning trial. This means that when training has reached asymptote, cue A will have a larger proportion of the total associative strength available and produce a stronger CR. Furthermore, if both cues are assigned equal salience, then at asymptote $V_A + V_B = \lambda$. Thus it follows that V_A will be less than the associative strength of a cue conditioned in isolation.

Arguably, a special form of overshadowing is blocking, which was first demonstrated by Kamin (1968; see also: Merchant & More, 1973; Dickinson, Shanks, & Evenden, 1984; Jennings & Kirkpatrick, 2006; Kamin, 1969; Prados et al., 2013; Sahley, Rudy & Gelperin, 1981; Shanks, 1985; Smith & Cobey, 1994; Suiter & LoLordo, 1971; vom Saal & Jenkins, 1970) and refers to the finding that learning about the relationship between cue B and an outcome is impaired if cue B is presented with cue A that has previously been paired with the outcome (A+ → AB+).

Kamin (1968) demonstrated blocking using a shock conditioning procedure in rats. First, he divided the rats into two groups: Blocking and Control. In the Blocking Group, during Stage 1, rats were exposed to cue A (e.g. a tone) which reliably predicted an outcome (foot shock). Then, in Stage 2, rats were presented with compound AB (e.g. tone + light) which was paired with the same outcome as Stage 1. However, in the Control Group, Stage 1 training was omitted. After Stage 2, both groups were presented with cue B (e.g. light) by itself, and fear, as measured by conditioned suppression was recorded. Kamin found that rats in the Blocking Group exhibited very little suppression to cue B; learning had been almost completely *blocked* by cue A. In contrast, rats in the Control Group displayed 'fear' to cue B, despite the fact that they had received an identical number of cue B → shock pairings as the Blocking Group. The Rescorla-Wagner (1972) model is able to explain these findings because training between a tone and a foot shock results in the tone's associative strength reaching asymptote. Therefore, when the light is presented in compound with the tone, no learning takes place since there is no discrepancy between the

observed and the expected values ($\lambda - \sum V$); the outcome (foot shock) is perfectly predicted already.

On the other hand, there are other phenomena in associative learning that the Rescorla-Wagner (1972) model finds harder to explain because it does not provide an explanation for how cue-specific learning rates can be adjusted as a consequence of experience. A classic example of this is latent inhibition (LI) in which learning about the relationship between a cue and an outcome is impaired if the cue has previously been presented in the absence of the outcome (see: Crowell & Anderson, 1972; Schnur & Lubow, 1976; Lubow, Markman & Allen, 1968; Lubow & Moore, 1959; Solomon & Corbit, 1974; Della Casa, Höfer, Weiner, & Feldon, 1999).

In Stage 1 of the experiment by Lubow and Moore (1959), for example, goats and sheep were pre-exposed to a non-reinforced stimulus (e.g. a flashing light). During Stage 2, the flashing light and a novel stimulus (e.g. a moving rotor) were both (separately) paired with a shock. The results revealed that more trials were required to reach criterion (10 CRs) if the stimulus had been pre-exposed relative to if it had not. Consequently, LI reveals that mere exposure to a cue influences its associability. This finding constitutes a challenge to the Rescorla-Wagner model, which provides no scope for learning to affect variations in cue associability, although Rescorla and Wagner (1972) acknowledged the likely influence of α.

1.2 Wagner (1978, 1981)

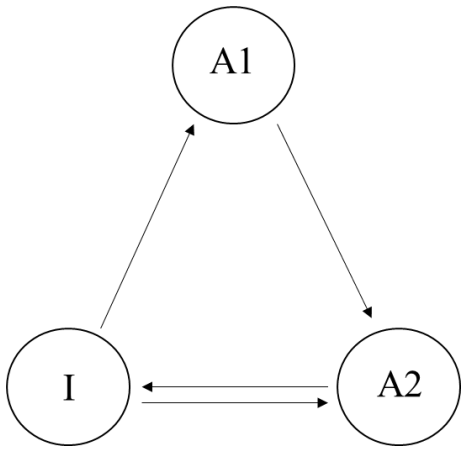
In 1978, Wagner proposed a revised version of the Rescorla-Wagner (1972) model as a model of short-term memory (STM). Like the Rescorla-Wagner model, Wagner's model used summed prediction error ($\lambda - \sum V$) to describe changes in the associative relationship between a cue (CS) and an outcome (US). However, it also incorporated an additional prediction error which described the processing of the cue. Together the equation is as follows, where l is the asymptote of associability of the cue, and S_v refers to how well the cue is predicted by all stimuli available on the trial (e.g. contextual cues).

$$\Delta V = \alpha \times (l - S_v) \times \beta \times (\lambda - \sum V) \qquad \textbf{Equation 1.2}$$

In 1981, Wagner revised his model which has become known as the 'Sometimes Opponent Processes' (SOP) model. Within this model stimuli are represented by elements that can be in one of three different activity states: a limited capacity central activity state (A1), a peripheral activity state (A2) with a larger capacity, or an inactive state (I) (see Figure 1.1). Wagner proposed that when a cue is initially presented, the elements of the cue will move from I into A1 causing the organism to respond to it. However, after this initial presentation, elements of the cue decay from A1 into A2 where the they are still active but responding to them is weaker. From here, the cue's elements will eventually move into I, where they are inactive but can be reactivated and move back into A1.

Wagner (1981) proposed that if two cues have elements in the A1 state at the same time (e.g. tone + shock), excitatory associations can be formed between

them. Furthermore, if an association has previously been established (e.g. tone → shock), exposure to the tone will prime the shock's representational elements into A2, without first entering A1. Inhibitory learning is established when a CS is in the A1 state and the US is in an A2 state. No learning will accrue when the CS is in the A2 state.



Cue	Outcome	Association change
A1	A1	Excitatory
A1	A2	Inhibitory
A2	A1	No learning
A2	A2	No learning

Figure 1.1 *Wagner's (1981) SOP model and learning states table*

The SOP model explains overshadowing by suggesting that when cues 'a' and 'B' are conditioned in compound, the elements of the less salient cue (a) are less likely to be recruited into or remain in A1, permitting more learning about the cue B → outcome relationship. This means that when tested individually there will be a stronger CR towards cue B than cue a. The model also explains blocking by suggesting that if a cue is paired alone with an outcome, a strong excitatory association will be established between them since the elements of both A and O are in A1 at the same time. After repeated pairings, the presentation of A causes a large number of O's elements to enter into A2 which

means that when A and the blocked cue (B) are presented simultaneously, O's elements cannot enter into A1 and therefore the B → O association will not be formed.

Unlike the Rescorla-Wagner (1972) model, Wagner's (1981) model of associative learning is able to explain LI in terms of context-cue associations. Wagner's model proposes that during the pre-exposure stage, the context enters into an association with the CS; therefore, during conditioning the CS is less likely to enter into A1 and consequently changes in associative strength proceed more slowly. As a consequence, this explanation is easily able to explain the context sensitive nature of LI because if the context is changed between the pre-exposure stage and test stage, the CS is not better predicted by the context and learning proceeds at the same rate for both conditions (Miguez, Soares & Miller, 2015).

1.3 Mackintosh (1975)

In contrast to the previous models, the model of associative learning proposed by Mackintosh (1975) claims that stimulus processing changes as a consequence of how well a stimulus predicts subsequent events, rather than the extent to which a stimulus is predicted by preceding events. The Mackintosh model does this by allowing a cue's associability to vary as a consequence of its predictive validity by suggesting that attention will increase towards the cue that is the best predictor of an outcome on that trial and decrease towards all other cues. This has become known as the predictiveness principle and according to Le Pelley, Mitchell, Beesley, George and Wills (2016), "*the predictiveness principle refers to the idea that cues become more psychologically salient as a result of their predictiveness with respect to important outcomes; more attention will be allocated to predictive cues than nonpredictive cues*".

Mackintosh (1975) proposed that the change of associative strength for cue A (ΔV_A) is determined by Equation 1.3, where α is a learning rate parameter that determines a cue's associability and reflects the amount of attention it attracts, θ is a learning rate parameter based on the outcome (between 0 & 1), and λ refers to the asymptotic value supported by the outcome. Other models that employ the same principle also exist (see: Kruschke, 1992, 2001, 2006; Lovejoy, 1968; Schmajuk & Moore, 1985; Sutherland & Mackintosh, 1971; Trabasso & Bower, 1968; Zeaman & House, 1963).

$$\Delta V_A = \alpha_A \theta (\lambda - V_A) \qquad \textbf{Equation 1.3}$$

The Mackintosh (1975) model updates cue A's associability using the following rules (see Equations 1.4 & 1.5), where V_X is the associative strength of all other stimuli present on the trial apart from cue A. Informally, this means that the amount of attention directed towards a cue will increase if it the best available predictor of reinforcement, and decrease otherwise. This feedback system essentially has the effect of allowing the individual to "tune out" irrelevance in the world, ensuring that organisms will preferentially attend to signals which are good predictors of biologically important outcomes at the expense of irrelevant signals, and thus control behaviour. This ability to attend to predictive cues and ignore less predictive cues has been referred to as exploitative attention (see Beesley et al., 2015) because it allows organisms to exploit their prior knowledge about a cue. Put another way, organisms direct more attention towards stimuli that predict the outcome with the least uncertainty.

$$\Delta \alpha > 1 \text{ if } (\lambda - V_A < \lambda - V_X) \qquad \textbf{Equation 1.4}$$

$$\Delta \alpha < 1 \text{ if } (\lambda - V_A \geq \lambda - V_X) \qquad \textbf{Equation 1.5}$$

Similar to Wagner's SOP (1981) model of associative learning, the Mackintosh (1975) model also provides explanations for overshadowing, blocking and latent inhibition. The Mackintosh model explains overshadowing by claiming that learning about the more salient cue (e.g. $\alpha A = .7$ & $\alpha B = .3$) will proceed faster because it has a higher associability. Consequently, this means that when training has reached asymptote, cue A will have more associative strength and produce a stronger CR. To explain blocking, the Mackintosh (1975) model proposes that, relative to cue A there is a large

prediction error for cue B at the outset of Stage 2. Consequently, attention to cue B will fall, limiting the extent to which it can enter into an association with the outcome in Stage 2 – blocking it. Finally, the Mackintosh (1975) model provides an explanation for LI by suggesting that when cue A is pre-exposed, the context and cue A become predictors of nothing. As the context is a better predictor of nothing than the cue (because it is more frequently paired with nothing), the cue will suffer a reduction in associability, consequently subsequent learning about this cue will be slowed.

More evidence for the influence of attention during associative learning is provided by the observation that learning between a cue and outcome proceeds more slowly if the cues have previously been presented in an uncorrelated fashion – learned irrelevance. An example of learned irrelevance was demonstrated by Mackintosh (1973; see also: Baker & Mackintosh, 1977; Myers et al., 2000; Orosz et al., 2007; Orosz et al., 2008; Orosz et al., 2011) who presented one group of rats with uncorrelated cue and outcome presentations, but for a second group this uncorrelated training was omitted. During the test phase when a predictive relationship was established between the cue and outcome, it was found that conditioning was more successful in the group who did not previously experience the uncorrelated presentations of the cue and the outcome.

An interpretation of the learned irrelevance effect by the Mackintosh (1975) model is that the rats which received the uncorrelated cue and outcome presentations learned that the cue was a poorer predictor of the outcome than the context (or, at least no better a predictor of the outcome), and therefore α reduced below its starting value. However, an alternative explanation of learned

irrelevance has been put forward by Bonardi & Ong (2003) who suggested that pre-exposure to the cue and outcome alone may have retarded learning. They suggest that the effect is no more than the sum of the CS and US pre-exposure effects.

A way in which to circumvent the issues that have dogged the interpretation of the learned irrelevance effect is to employ a procedure that matches experimental and control groups on the number of times that the cue and the outcome are exposed. Such a procedure is employed in studies of the IDS/EDS effect (e.g. Birell & Brown, 2000; Dias, Robbins & Roberts, 1997; Eimas, 1966; George & Pearce, 1999; Mackintosh & Little, 1969; Oswald et al., 2001; Roberts, Robbins & Everitt, 1988; Rogers, Andrews, Grasby, Brooks & Robbins, 2000; Shepp & Eimas, 1964; Shepp & Schrier, 1969). During Stage 1 of a typical IDS/EDS task, subjects are trained on a discrimination in which stimulus compounds comprise two elements drawn from two different stimulus dimensions. One dimension (e.g. colour) is predictive for solving the discrimination but the other dimension (e.g. orientation) is irrelevant. In Stage 2, subjects are presented with stimulus compounds constructed from novel stimuli drawn from the same two dimensions employed in Stage 1. In the IDS group the same dimension that was predictive in Stage 1 (e.g. colour) is also predictive for solving the discrimination in Stage 2. However, for the EDS group the contingency is reversed so that the dimension that was irrelevant for solving the discrimination in Stage 1 (e.g. orientation) is now predictive in Stage 2. Results reliably find that subjects in the IDS group solve the discrimination in Stage 2 faster than the EDS group (for failures to obtain these results, see: Couvillon, Tennant, & Bitterman, 1976; Hall & Channell, 1985).

For example, in the study by Mackintosh and Little (1969), two groups of pigeons were presented with three lines which could differ in colour (yellow or red) and orientation (0 and 90 degrees). The pigeons needed to learn which colour-orientation compounds were predictors of food or the absence of food. For half of the pigeons, the colour of the lines predicted the outcome of the trial, whilst their orientation was irrelevant; for the remaining pigeons the contingency was reversed. Once the initial discriminations had been learned, the pigeons were transferred to a new discrimination using novel cues (blue & green lines presented at 45 & 135 degrees). For the IDS group the dimension that was predictive in Stage 1 remained predictive in Stage 2; but for the EDS group the dimension that was predictive in Stage 1 was now irrelevant in Stage 2. The results revealed that pigeons in the IDS group learned the task in Stage 2 more rapidly than the pigeons in the EDS group.

The IDS/EDS effect demonstrates that a cue's predictive validity influences the extent to which it is subsequently able to engage in learning. The IDS/EDS effect cannot be accounted for in terms of the straightforward transfer of associative strength (e.g. Rescorla & Wagner, 1972) because in Stage 2 all cues are novel; thus, given appropriate counterbalancing, any generalisation of training from Stage 1 should be equivalent across the cues. Therefore, analyses of the IDS/EDS effect have appealed to changes in attention towards predictive and irrelevant cues during Stage 1 of training. According to the Mackintosh (1975) model, the amount of attention directed towards a stimulus is able to generalise to other stimuli that are similar. Consequently, the attentional bias established in Stage 1 towards the predictive dimension generalises more readily towards new exemplars of the same dimension in Stage 2. Hence, in the IDS

condition, subjects will enter Stage 2 with an attentional bias towards the predictive dimension which facilitates discrimination, but in the EDS group participant's attention is biased towards the newly irrelevant dimension and as a result discrimination learning will be slower.

As noted, the IDS/EDS effect can sidestep an explanation in terms of straightforward transfer of associative strength by making a change in the cue between Stage 1 (in which the putative attentional bias was established) and Stage 2 (in which the attentional modulation of learning and performance is assessed). However, in recent years, studies of attentional modulation of learning and performance in human participants have more frequently applied a strategy in which the nature of the outcome is changed between Stage 1 and 2, rather than the cues, in order to achieve the same kind of sidestep. In a learned predictiveness task participants are presented with compounds of cues that comprise one cue that is predictive of the outcome and one cue that is irrelevant. Findings consistently reveal that cues which are predictive in Stage 1 are better able to enter into associations in Stage 2 with new outcomes, and attract more overt attention than irrelevant cues (see: Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2016; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al., 2012).

For example, Le Pelley and McLaren (2003) demonstrated the learned predictiveness effect using an allergy prediction paradigm in which participants played the role of a food allergist determining the food allergies of a fictitious patient (see Table 1.1). During Stage 1, different foods (A, B, C, D, V, W, X, Y) were presented in compound and paired with different allergic reactions

(outcome 1 (O1) or outcome 2 (O2)). On each trial one cue (A-D) was perfectly predictive of an allergic reaction whilst the other cues (V-Y) were paired equally often with O1 as O2, and were therefore irrelevant. In Stage 2, participants were asked to learn about the food allergies of a new fictitious patient. During this stage, cues were combined into novel combinations comprising one previously predictive cue (A-D) and one previously irrelevant cue (V-Y), and paired with new outcomes (O3 or O4). Crucially, in Stage 2, the previously predictive cues (A-D) were just as relevant about O3 and O4 as were the previously irrelevant cues (V-Y). Thus, any differences in learning about the predictive relationships between the cues and O3 and O4 must be as a consequence of the transfer of a bias established during training in Stage 1. A subsequent causal judgement test revealed that participants learned more about the associative relationship with outcomes O3 and O4 between cues that were predictive of the outcome in Stage 1 than cues that were irrelevant in Stage 1.

Table 1.1 *Experimental design for Le Pelly and McLaren (2003)*

Stage 1	*Stage 2*	*Test*
AV→O1	**AX→O3**	**AC**
BV→O2	**BY→O4**	**BD**
AW→O1	**CV→O3**	**VX**
BW→O2	**DW→O4**	**WY**
CX→O2	**EF→O3**	**EH**
DX→O1	**GH→O4**	**FG**
CY→O2	**IJ→O3**	**IJ**
DY→O1	**KL→O4**	**KL**

Like the IDS/EDS effect, the difference in learning rate during Stage 2 between previously predictive and previously irrelevant cues is difficult to account for in terms of the transfer of associative strength since the outcomes are novel. Instead, the result has been taken to reflect the development of an attentional bias in Stage 1. According to the Mackintosh (1975) model, during Stage 1 attention increases towards cues A-D which reliably predict the outcome of a trial, and decrease towards cues V-Y which are irrelevant. Consequently, at the outset of Stage 2, participants will learn the new associative relations quicker for stimuli A-D than V-Y because they attract more attention.

The studies that have been described thus far have employed associability as a measure of attention. However, associability is only an indirect measure of attention as changes in attention are inferred from variations in the amount that is learned about stimuli. Furthermore, it has been argued that using associability alone does not allow purely associative explanations to be ruled out (e.g. Honey, Close and Lin, 2010; Honey & Ward-Robinson, 2002). Consequently, in recent years there has been a move towards using eye-tracking to measure more directly how much overt visual attention individual cues attract when presented in compound, rather than relying on associability, which may be a function of other learned characteristics rather than attention (e.g. Lin & Honey, 2010). However, it should be noted that although eye-tracking is a behavioural measure which is commonly accepted as representing selective attention, eye-tracking only measures overt attention even though it is commonly accepted that people are able to covertly shift their attention without moving their eyes. On the other hand, Deubel and Schneider (1996) claim that eye movements and attentional shifts are generally accepted as being tightly coupled. They found that

participants were better able to discriminate between two symbols (forwards & backwards facing 'E') when the discrimination stimulus and saccade stimulus (where they had to look) referred to the same object.

A study that used eye-tracking to monitor changes in attentional allocation during a learned predictiveness task was conducted by Le Pelley et al. (2011; see also: Beesley et al., 2015; Haselgrove et al., 2015; Le Pelley et al., 2013; Mitchell et al., 2012). In their study they used a similar experimental design to that employed by Le Pelley and McLaren (2003, see Table 1.2), but with a different cover story. In Stage 1, participants were required to predict which of two auditory outcomes (O1 & O2) would follow a pair of nonsense words. The predictive validity of cues in Stage 1 was varied to establish cues A, B, C and D as reliably predictive of O1 or O2, and cues V, W, X and Y as irrelevant. In Stage 2, cues were combined into novel combinations and paired with novel outcomes (O3 & O4). It was found during the test stage that cues which were established as predictive in Stage 1 (A, B, C & D) attracted longer dwell times and were better able to enter into associations with outcomes O3 and O4 compared with cues that were established as irrelevant in Stage 1 (V, W, X & Y). Le Pelley et al. interpreted these results as providing support for the idea that attention came to be acquired more to the stimuli that were predictive of the trial outcome than the stimuli that were irrelevant. This interpretation is consistent with the theory of associative learning proposed by Mackintosh (1975).

Table 1.2 *Experimental design for Le Pelly, Beesley & Griffiths (2011)*

Stage 1	*Stage 2*	*Test*
AV→O1	**AX→O3**	**AC**
BV→O2	**BY→O4**	**BD**
AW→O1	**CV→O3**	**VX**
BW→O2	**DW→O4**	**WY**
CX→O2		
DX→O1		
CY→O2		
DY→O1		

1.4 Pearce and Hall (1980)

Using eye-tracking and a similar task to Le Pelley et el. (2011), Hogarth et al. (2008; for a similar result see: Trick, Hogarth & Duka, 2011) obtained results which cannot be explained by the Mackintosh (1975) model and instead provide support for the attentional model of associative learning proposed by Pearce and Hall (1980) which fundamentally conflicts Mackintosh's model. In Hogarth et al.'s design, the compound of patterns A and X was always followed by an outcome (AX+), compound C and X was always followed by the omission of an outcome (CX-), and compound B and X was followed by an outcome on 50% of the trials and followed by an omission on the other 50% of the trials (BX+/-). Hogarth et al. found that participants directed more dwell time towards the unpredictive cue B relative to cues A and C which were perfectly predictive of the outcome and the absence of the outcome respectively. As will be seen, these results can be explained using a model of attention and learning that conflicts with the Mackintosh model: the Pearce-Hall (1980) model.

Pearce and Hall (1980) proposed a model of associative learning which argues that attention is guided by predictive accuracy, not stimulus relevance as proposed by Mackintosh (1975). A cue's associability is equal to the absolute difference between the magnitude of the outcome and the sum of the associative strength of all the cues present on that trial. This means that more attention will be directed towards cues that are followed by surprising outcomes. The change in associative strength for cue A (ΔV_A) between a cue → outcome pairing is determined by Equation 1.6, where S is a parameter (between 0 & 1) which is

dependent on the cue's intensity, α_A is the associability that cue A receives on a trial, and λ is the intensity of the outcome.

$$\Delta V_A = S_A . \alpha_A . \lambda \qquad \textbf{Equation 1.6}$$

The Pearce-Hall (1980) model claims that associability is modified by experience; therefore, associability will be high at the start of training when stimuli are novel, but this high salience is only maintained if the cue is followed by a surprising outcome, see Equation 1.7, where α_n is the amount of attention a stimulus will attract on trial n, λ_{n-1} is the magnitude of the outcome on the preceding trial, and $\sum V_{n-1}$ is the associative strength of all the stimuli present on that trial. Consequently, this model predicts that α will reduce with training with a consistent outcome, but will be sustained if the outcome is surprising on each trial (e.g. partial reinforcement) because presenting an outcome only on some trials means that the expression $\lambda - \Sigma V$ always has a positive value.

$$\alpha_n = (\lambda_{n-1} - \sum V_{n-1}) \qquad \textbf{Equation 1.7}$$

Support for this prediction was provided by Haselgrove, Esber, Pearce and Jones (2010). During this experiment rats were conditioned with four auditory stimuli, two which were always paired with food and two that were paired with food on 50% of the trials. After training, rats were given a discrimination task in which two novel compounds were presented comprising one continuously reinforced cue and one partially reinforced cue. Results

revealed that cues which were partially reinforced during the training stage were better discriminated between compared with cues that had been continuously reinforced.

In addition to using a cue's associability as a measure of the amount of attention it attracts, another approach is to measure the strength of the orienting response the cue elicits. Wilson, Boumphrey and Pearce (1992) found evidence that overt attention increased towards a cue when it was established as an imperfect predictor of the outcome, compared with when it was a perfect predictor. In this experiment rats were initially given serial conditioning with either a light-tone-food sequence or light-tone-nothing sequence, where the light was always followed by a tone. In Stage 2, Group Consistent received the same training, but Group Inconsistent received the sequences light-tone-food and light-nothing, where the light was an uncertain predictor of the outcome. Results revealed that the second phase of training enhanced the orienting response towards the light. This increase in overt attention was also reflected by an increase in associability as revealed by a subsequent test in which it was paired with food.

There is also a well-established neural basis that supports the preferential processing of uncertain cues, as predicted by the Pearce-Hall (1980) model. This has become known as the prediction error hypothesis and was first proposed by Montague, Dayan and Sejnowski (1996). The hypothesis suggests that the neurotransmitter dopamine facilities reward-based learning by signalling prediction errors. Schultz, Dayan and Montague (1997) found that dopamine fires under several conditions: dopamine increases on the receipt of an unpredicted reward, increases in response to the first presentation of a novel

predictor which has no predictive value, and decreases below background level if an expected reward is not received (although the latter is somewhat contrary to predictions made from the Pearce-Hall (1980) model). These neural responses have been found in humans in the anterior insula (Preuschoff, Quartz & Bossaerts, 2008; De Martino, Kumaran, Holt & Dolan, 2009; d'Acremont et al., 2009), striatum (Preuschoff et al., 2006), and anterior cingulate cortex (Behrens, Woolrich, Walton & Rushworth, 2007). Neural signals of uncertainty have also been detected in the non-human primate parietal cortex (Kiani & Shadlen, 2009) and ventral midbrain (Fiorillo, Tobler, & Schultz, 2003), and rodent orbitofrontal cortex (Kepecs, Uchida, Zariwala & Mainen, 2008).

Additionally, research has suggested that uncertainty is reflected in pupilology. The link between pupil dilation and decision making has been established with regards to uncertainty, reward-prediction errors and surprise (Preuschoff, 't Hart & Einhäuser, 2011). Lavín, San Martín and Jubal (2014) found that pupil dilation changes were influenced by learned uncertainty and surprise, regardless of the magnitude of the feedback. According to Aston-Jones and Cohen (2005; see also: Einhäuser, Stout, Koch & Carter, 2008; Jepma & Nieuwenhuis, 2011; Kuipers & Thierry, 2011), pupil dilation has been found to be linked to locus coeruleus and noradrenaline activity which is related to uncertainty signalling (Rajkowski et al., 1994; Yu & Dayan, 2005).

Similar to the Mackintosh (1975) model, the Pearce-Hall (1980) model is able to explain effects such as overshadowing, blocking and LI. Overshadowing can be explained in much the way as the Mackintosh model by suggesting that learning will proceed at a faster rate towards more salient cues. If α is .7 for cue A but only .3 for cue B, learning about the cue A $\rightarrow$ outcome relationship will

be learned quicker because it has higher associability. The Pearce-Hall model suggests that during a blocking procedure, in Stage 1, cue A is established as a good predictor of the outcome. This means that when cue X is conditioned in compound with cue A, the outcome is not surprising and consequently does not produce a prediction error. Consequently, the associability of the added cue X, will quickly be driven to a low value. Finally, to accommodate LI the Pearce-Hall model suggests that during the pre-exposure phase the α of cue A will fall to zero as it is consistently followed by no-outcome. This means that in Stage 2 when cue A is paired with an outcome, learning about cue A will proceed at a slower rate (at least initially) than a novel cue B.

On the other hand, the Pearce-Hall (1980) model isn't able to explain all of the phenomena that the Mackintosh (1975) model accommodates. The Pearce-Hall model cannot explain learned irrelevance, the IDS/EDS effect or the learned predictiveness effect because it predicts that although the predictive cue/dimension will attract more attention initially, this will reduce as the cue is established as a good predictor of the outcome. Consequently, this means that as the experiment progresses, the amount of attention directed towards irrelevant cues should surpass predictive cues, but this is not what experimental findings reveal (see: Eimas, 1966; George & Pearce, 1999; Mackintosh & Little, 1969; Oswald et al., 2001; Roberts, et al., 1988; Shepp & Eimas, 1964; Shepp & Schrier, 1969).

Conversely, there are phenomena that cannot be explained using the Mackintosh (1975) model that can be easily interpreted using the Pearce-Hall (1980) model. The best example of this is Hall-Pearce negative transfer where conditioning to a cue established with a strong outcome is impaired if it has been

previously paired with a weaker outcome (see: Aryes, Moore & Vigorito, 1984; Hall & Pearce, 1979; Griffiths, Johnson & Mitchell, 2011; Hall & Pearce, 1982; Kasprow, Schachtman & Miller, 1985; Schachtman, Channell & Hall, 1987; Savastano, Yin, Barnet & Miller, 1998 ; Swartzentruber & Bouton, 1986; Young & Fanselow, 1992).

In the experiment reported by Hall and Pearce (1979) rats were given trials in which a tone was paired with a strong foot shock. The results showed that the CR to the tone was established more slowly when it had previously served as a signal of a weak shock than when it was novel. Hall and Pearce suggested that the pre-conditioned tone took longer to learn about in Stage 2 because the processing capacity for the tone was attenuated as consequence of establishing it as a good predictor of an event in the past as predicted by the Pearce-Hall (1980) model. Although, the effect is attenuated if the CS is extinguished prior to strong shock training. However, the Mackintosh (1975) model is not able to explain Hall-Pearce negative transfer because it predicts that responding should be enhanced not diminished since the cue has already been established as a good predictor of the outcome.

Both the Mackintosh (1975) and Pearce-Hall (1980) models have received much empirical support but neither theory has been able to oust the other (Mackintosh model: learned predictiveness, learned irrelevance, IDS/EDS. Pearce-Hall model: negative transfer, partial reinforcement). On this basis it seems plausible to suggest that there may be more than one mechanism responsible for governing how associability changes as a result of experience. Arguably the most comprehensive attempt at creating a hybrid model that accommodates both the Mackintosh mechanism and the Pearce-Hall

mechanism was proposed by Le Pelley (2004; also see: George & Pearce, 2012; Le Pelley, 2010; Pearce & Mackintosh, 2010; Pearce, George & Redhead, 1998).

1.5 Le Pelley (2004)

Le Pelley (2004) proposed a hybrid model which reconciles the two conflicting attentional models of associative learning (Mackintosh, 1975; Pearce-Hall, 1980) by postulating that there are two different types of attention (exploitative & explorative) which combine to determine a cue's overall salience. Consequently, it calculates two saliencies for a cue, one for the purpose of stimulus selection which functions by the mechanism proposed in the Mackintosh model, and the other based on its exposure history which functions by the mechanism proposed in the Pearce-Hall model.

According to the Mackintosh component of the model, α is a learning rate parameter that determines a cue's associability and reflects the amount of attention it attracts. Therefore, this component determines how much associability should be directed towards a stimulus compared to other available stimuli (attentional associability α). On the other hand, the Pearce-Hall component claims that a cue's associability is equal to the absolute difference between the magnitude of the outcome and the sum of the associative strength of all the cues present on that trial. Therefore, this component determines how much associability should be attributed towards a cue on the basis of its exposure history (salience associability σ). Together, α allows an animal to identify which stimuli should be learned about, and σ regulates how much should be learned about a stimulus.

The equations that determine the change in associative strength for cue A can be seen in Equation 1.8 for excitatory learning (if R is positive), and Equation 1.9 for inhibitory learning (if R is negative), where V and $\overline{V}$ refer to

excitatory and inhibitory associative strength, β_E is the learning-rate parameter for excitory learning, β_I is a learning-rate parameter for inhibitory learning, and R is the strength of the reinforcer. The model also uses a summed error term, like the Rescorla-Wagner (1973) model, as well as individual error terms for all cues present on a trial.

$$\Delta V_A = \alpha_A \sigma_A \beta_E . (1 - V_A + \overline{V}_A) . |R| \qquad \textbf{Equation 1.8}$$

$$\Delta \overline{V}_A = \alpha_A \sigma_A \beta_I . (1 - \overline{V}_A + V_A) . |R| \qquad \textbf{Equation 1.9}$$

With appropriate parameterization, this hybrid approach to calculating a cue's salience enables the Le Pelley (2004) model to explain not only phenomena that can be accommodated by both the Mackintosh (1975) model and Pearce-Hall (1980) model (e.g. blocking, overshadowing & LI), but also phenomena that provide exclusive support for the Mackintosh model (e.g. learned irrelevance, IDS/EDS & learned predictiveness) or the Pearce-Hall model (e.g. negative transfer).

The Le Pelley (2004) model explains cue competition phenomena well. For example, it explains blocking by suggesting that when both cues are presented in compound (AB+), learning about the added cue (B) is calculated using three mechanisms – one from all three models: Rescorla-Wagner (1972), Mackintosh (1975) and Pearce-Hall (1980). First, since the outcome is already fully predicted by cue A, means that it the error term will be small and learning about cue B will be slow. Second, since cue A is historically a better predictor of the outcome than cue B, the attentional associability of cue B (α_B) will decrease,

reducing the amount that it is learned about. Third, because the outcome is well predicted on compound trials by cue A will result in the salience associability for cue B (σ_B) decreasing and learning proceeding slowly about cue B.

To explain learned irrelevance, the Le Pelley (2004) model claims that α will be low because the cue is a worse predictor of reinforcement than the context. However, because the context and cue compound are a poor predictor of the outcome, σ will be high. This means that even when the cue is paired with the outcome future learning about the cue will be slow because α is low.

The model explains IDS/EDS the same way as defined by the Mackintosh (1975) model. During Stage 1 of an IDS/EDS task, α will increase towards the stimuli that are predictive for solving the discrimination (e.g. colour) and by the end of Stage 1 σ will be equivalently low to all the stimuli because the outcome is well-predicted. This means that at the outset of Stage 2, learning will proceed faster towards the novel predictive dimension because it has more features in common with the predictive dimension from Stage 1 than the novel irrelevant dimension. By the same token, the low associability accrued by the irrelevant stimuli in Stage 1 will generalise to the irrelevant dimension in Stage 2 because they have more features in common.

Similarly, Le Pelley's (2004) model explains the learned predictiveness effect by suggesting that α will increase towards predictive cues because they are a better predictor of the outcome compared with irrelevant cues. On the other hand, σ will be equivalently low to all stimuli because the outcome is fully expected as the cue is a good predictor of the outcome. This means that when cues are combined in novel combinations in Stage 2 and paired with novel

outcomes, future learning will proceed more rapidly for the predictive cues because α is higher compared to the irrelevant cues.

Moreover, the Le Pelley (2004) model doesn't just provide accounts of phenomena that can be explained by the Mackintosh (1975) model, it can also explain Hall-Pearce negative transfer which provides support for the Pearce-Hall (1980) model. During a negative transfer design, participants experience pre-training in which a weaker outcome is paired with a cue (cue → us) before being paired with a stronger outcome (cue → US). The Le Pelley model suggests that during the pre-training, σ decreases because prediction error is low since the cue perfectly predicts the outcome. However, since the cue is the best available predictor of the outcome, the cue's attentional associability (α) will increase. This means that on the following cue → US trials, the pre-trained group will have a considerably lower σ_A compared to a group that received no pre-training and only a slightly higher α_A, since its starting value is near maximum. Therefore, the Le Pelley model anticipates that learning about the cue → US should be slower if preceded by cue → us pre-training.

There are also other phenomena for which the Le Pelley (2004) model can explain some, but not all of the findings associated with the effect. For example, the Le Pelley model explains LI by suggesting that although non-reinforced pre-exposure of a cue does not reduce its attentional associability (α), it does reduce its salience associability (σ) because the cue perfectly predicts no-outcome, so prediction error is low. This means that on subsequent cue → outcome pairings, learning about the relationship will proceed more slowly compared to a cue that has not been pre-exposed, and therefore experienced a

reduction in salience associability (σ). However, the Le Pelley model struggles to provide an explanation for the context specificity of LI (as do the Mackintosh (1975) & Pearce-Hall (1980) models) without making additional assumptions. For example, it could be assumed that cues presented in different contexts (e.g. cue A in context X & cue A in context Y) are perceived as different cues with common elements (Ax & Ay), and consequently there will be a generalisation decrement between them.

Furthermore, Le Pelley's (2004) hybrid model is not easily able to accommodate findings which demonstrate that a cue's learned value influences performance. Störmer, Eppinger and Li (2014) conducted a study in which participants had to find the letter 'T' amongst letter 'L' distracters and indicate its orientation. For each correct response participants earned money, however, the amount of money that they earned was dependent on the colour that the 'T' was (e.g. red T = 5¢, green T = 1¢). What they found was that over the course of the experiment, participants responded faster on trials in which a high value target was presented (red T). These findings suggest that learning which stimuli are associated with high-value rewards biased attention towards these targets.

A different procedure was employed by Anderson, Laurent and Yantis (2011; see also: Anderson, Faulkner, Rilee, Yantis & Marvel, 2013; Anderson, Laurent & Yantis, 2013, 2014; Anderson, Leal, Hall, Yassa & Yantis, 2014; Anderson & Yantis, 2012; Laurent, Hall, Anderson & Yantis, 2015; Qi, Zeng, Ding & Li, 2013; Roper, Vecera & Vaidya, 2014; Sali, Anderson & Yantis, 2014; Wang, Yu & Zhou, 2013) who presented participants with six circles of different colours and amongst them was the target circle which was either red or green. During the training stage participants were required to respond as quickly as

they could to indicate the orientation of the line (horizontal or vertical) inside the target circle. If they responded correctly and fast enough, participants were rewarded with a monitory amount that corresponded to the colour of the target circle (e.g. red circle = 5¢, green circle = 1¢). Then in the test stage participants were required to respond to the shape of the target cue. Results showed that despite no rewards being given in the test stage, participants were slower to respond if one of the distracter shapes was in the same colour (now task irrelevant) that had previously been paired with a high value reward in the training stage. This suggests that the association formed between colour and reward increased the amount of automatic attention that it captured even when no longer task-predictive and presented separate from the target cue.

The model proposed by Le Pelley (2004) suggests that the rate of α_A change is influenced by the value of the outcome (λ) because early in training when α_A is small, a large reward will produce a big prediction error and accelerate learning. Therefore, at the start of training the model makes a correct prediction, more attention will be directed towards high-value predictors than low value predictors. However, as learning reaches asymptote, the most attention will be directed towards the best learned predictor of an outcome, not learned the value. For example, in the experiment reported by Anderson et al. (2011), red and green are both the best, and equivalent, predictors of 5¢ and 1¢ respectively. Thus, the amount of attention these colours capture, at asymptote, should be equivalent. However, a contemporary model proposed by Esber and Haselgrove (2011) is better able to incorporate the role of learned value.

1.6 Esber and Haselgrove (2011)

Esber and Haselgrove (2011) proposed a model that reconciles the influence of predictiveness and uncertainty into a single mechanism for attentional allocation. It does this by claiming that the salience (α) of a cue is made up of both sensory attributes (e.g. intensity) which are unacquired properties of the cue ($\emptyset$), and acquired salience which is based on the cue's associative strength, determined by its ability to predict reinforcement (ε), therefore, $\alpha = \varepsilon + \emptyset$. Increments in salience towards predictive cues result from an organism's attempt to track motivationally salient events, this is also true for uncertain cues. On the other hand, decrements in salience occur to the extent that a cue is predicted by preceding events in a manner akin to the analysis provided by Wagner (1978, 1981).

Following the Pearce-Hall (1980) theory, Esber-Haselgrove (2011) proposed that stimuli enter into separate association with reinforcement and non-reinforcement. According to Esber and Haselgrove, increases in the strength of the association and reinforcement proceed according to Equation 1.10; where β is a constant (between 0 & 1) that is determined by the motivational properties of the outcome and λ is the asymptote conditioning supported by the outcome. If the reinforcer is over-expected ($\lambda < (\sum V - \sum \bar{V})$), then the association will weaken; however, if reinforcement is under-expected ($\lambda > (\sum V - \sum \bar{V})$), the association will strengthen.

$$\Delta V = \alpha\beta(\lambda - (\sum V - \sum \bar{V})) \qquad \textbf{Equation 1.10}$$

To calculate the change in associative strength for cue → non-reinforcement pairings (Equation 1.11), first the asymptotic value is calculated by assuming that it is equal to the expectation of reinforcement minus the summed expectation of no-reinforcement ($\sum V - \sum \bar{V}$). Therefore, if a reinforcer is over-expected $\left(\lambda < (\sum V - \sum \bar{V})\right)$, the change in associative strength ($\Delta\overline{V}$) will be positive and the cue → no-reinforcer association will strengthen. On the other hand, if the reinforcer is under-expected $\left(\lambda > (\sum V - \sum \bar{V})\right)$, the $\Delta\overline{V}$ will be negative and the cue → no-reinforcer association will weaken.

$$\Delta\overline{V} = \alpha\beta((\sum V - \sum \bar{V}) - \lambda) \qquad \textbf{Equation 1.11}$$

The Esber-Haselgrove (2011) model then employs an additive rule to sum the associative strengths that a cue has with each reinforcer to determine the cue's overall salience ($\varepsilon = f(V_{\text{cue}\rightarrow\text{reinf 1}} + V_{\text{cue}\rightarrow\text{reinf 2}} + \cdots + V_{\text{cue}\rightarrow\text{reinf n}})$. By doing this, it is able to account for the superiority of partially reinforced cues by arguing that they enter into two associations (cue → reinforcement & cue → no reinforcement), the absolute values are then summed in order to determine a cue's overall associative strength.

Decrements in cue salience also occur, which is exemplified in phenomena such as learned irrelevance and latent inhibition. To account for this, the Esber-Haselgrove (2011) model claims that decrements in salience occur if a cue predicted by other events including the context. From this, a symmetrical image emerges where stimuli lose salience as a consequence of

being predicted by preceding events, and gain salience by being predictive of future events.

Like the hybrid account proposed by Le Pelley (2004), the Esber-Haselgrove (2011) model can accommodate phenomena that are explained by both the Mackintosh (1975) model and Pearce-Hall (1980) model (e.g. blocking & overshadowing), as well as phenomena that provide exclusive support for the Mackintosh model (e.g. learned irrelevance, IDS/EDS & learned predictiveness) or the Pearce-Hall model (e.g. negative transfer, partial reinforcement).

The Esber-Haselgrove (2011) model interprets the blocking effect as both the effect of its summed error term, but also the lack of any increase in salience to cue B due to its failure to gain associative strength. To explain overshadowing the Esber-Haselgrove model claims that, a) the unacquired higher intensity (Ø) of cue B means that it will have a higher salience (α), and therefore learning about the cue B → outcome relationship will be faster, and that b) the summed error term will limit the associative strength of cue a.

Like the Mackintosh (1975) model, the Esber-Haselgrove (2011) model is able to explain learned irrelevance by suggesting that α is low because learning about the cue is blocked by the context. Following on from the cue's low α, this means that learning about the cue → outcome relationship will proceed slower even when paired consistently. In line with this, the Esber-Haselgrove model explains the learned predictiveness effect by arguing that higher α will be directed towards cues that are established as better associates of the outcome.

The Esber-Haselgrove (2011) model explains LI by suggesting that when a cue is pre-exposed, the cue is well predicted by the context. This causes the

cue's salience (α) to drop, meaning that at the outset of Stage 2, when the cue is now paired with an outcome, learning about the cue → outcome relationship will proceed more slowly compared to a cue that has not been pre-exposed since that cue's salience will be higher. Thus, the effect of context change is accommodated without additional assumptions. A similar mechanism is proposed to explain negative transfer, and a measure of support for these accounts comes from the observations that both are attenuated with a context change. For example, Swartzentruber and Bouton (1986) showed that negative transfer is weakened if a context change is introduced between the two phases.

Unlike the Le Pelley (2004) model, the Esber-Haselgrove (2011) model is better able to explain learned value since it suggests that attention is a direct function of associative strength. The model states that the amount of learning that the outcome can support (λ) will be higher with a higher value outcome, and therefore salience (α) will be correspondingly greater, towards a higher-value stimulus. This means that the Esber-Haselgrove model is able to interpret the findings of Anderson et al. (2011) where participants were slower to respond on test trials in which the distractor shapes were the same colour that had previously been paired with a high-value reward during training.

1.7 Structure of the thesis

No single attentional model of associative learning can provide a harmonious account for all of the phenomena described. Although, the Esber-Haselgrove (2011) model was able to explain the largest number of phenomena because it reconciles the influence of predictiveness and uncertainty into a single mechanism which naturally incorporates learned value.

One of the clearest demonstrations of the influence of predictive validity on attentional bias is the learned predictiveness effect (see: Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al., 2012). Chapter 2 provides an exploratory investigation into changes in overt attention during learned predictiveness to determine if the effect could be established in our laboratory, and whether various measures of overt attention correlated with each other.

The learned predictiveness effect provides reliable support for the Mackintosh (1975) model, however, this is to be expected because studies which provide support for the Pearce-Hall (1980) model incorporate a degree of uncertainty into the experimental design which a learned predictiveness task doesn't traditionally include because predictive cues are 100% predictive and irrelevant cues are 100% irrelevant. Therefore, in Chapter 2 we manipulated the predictive validity of cues during a learned predictiveness task so as to render some of them imperfect predictors of reinforcement. Also, building on the methodology established in the first experiment we attempted to replicate the

findings obtained by Hogarth et al. (2008) which provide almost unique support for the Pearce-Hall effect in humans.

Prior to eye-tracking becoming more widely available as a measure of overt visual attention, associability was used because it is assumed that the speed at which a stimulus is learned about reflects the amount of attention it attracts and this is demonstrated in the IDS/EDS effect. Chapter 3 measured eye gaze during an IDS/EDS task to determine whether the effect results from a shift in overt attention from Stage 1 into Stage 2. It also investigated the influence of uncertainty, if predictive contingencies were not 100%.

Originally the Mackintosh (1975) and Pearce-Hall (1980) models began as rat models of behaviour which were later used to interpret the behaviour of a wider range of animals, including humans as it is assumed that they share an evolutionary lineage which extends to learning mechanisms. Thus far, there is a dichotomy between the two models with the majority of support for the Mackintosh model coming from human experiments and most evidence for the Pearce-Hall model coming from animal experiments. The aim of Chapter 4 was to establish a common experimental design to back-translate the methodology used in the learned predictiveness task in adults into children and animals to determine whether the effect exclusively provides support for the Mackintosh model or whether the attentional bias results from the methodology used to test participants.

Finally, recent models of associative learning place great emphasis on the role of predictive significance in the modulation of eye gaze during learning. The Mackintosh (1975) model, for example, claims that it is prediction success that

drives attentional bias and consequently future learning. Conversely, the Pearce-Hall model claims that prediction error drives future learning. However, although prediction has been emphasised in these explanations, it should be noted that the formal models of learning only employ associations and error terms to calculate differences in attention. Chapter 5 investigated whether prediction is necessary for learned variations in attention to be established.

Chapter 2:

Measuring attention during learned predictiveness tasks

Theories of associative learning claim that a cue's prior predictive history determines the amount of attention it attracts and to what extent that it is subsequently learned about (e.g. Mackintosh, 1975; Pearce & Hall, 1980). Existing studies that have employed eye-tracking methodology during a learned predictiveness task have focused largely on the amount of dwell time and the proportion of dwell time directed towards predictive and irrelevant cues as a measure of overt attention (see: Hogarth et al. 2008; Hogarth et al., 2009; Le Pelley et al., 2011; Le Pelley et al. 2013; Mitchell et al., 2012; Wills, Lavric, Croft & Hodgson, 2007). Other measures of eye gaze have not been researched to the same extent, including fixation count, the latency to make the first fixation and fixation omissions (where no fixations were made). Therefore, the aim of Experiment 1 was to demonstrate the learned predictiveness effect in our lab and to compare various measures of overt attention to determine whether they correlate with each other, and therefore tap into the same underlying construct – selective attention.

There has also been little focus on the relative speed of learning (as measured by task performance) and attentional bias development. This is important because it is an assumption of explanations of the overtraining reversal effect (ORE). In the ORE individuals are trained beyond asymptote on Stage 1 of an IDS/EDS experiment. It has been reliably found that overtraining makes IDSs easier, but EDSs more difficult. This implies that attention varies even after the discrimination has been solved. In addition, no research has investigated how measures of overt attention vary as a consequence of trial feedback when the trial was a) correct or b) preceded by a correct trial.

Therefore, a further aim of Experiment 1 was to serve as an exploratory study to provide information on these issues.

2.1 Experiment 1

The aim of Experiment 1 was to examine whether our lab was able to obtain variations in attention with stimuli that differed in predictive validity using a range of measures recorded by eye-tracking, including dwell time, proportion of dwell time, fixation count, proportion of fixation count, latency to first fixation and fixation omissions. From this, we wanted to determine whether all measures were equally representative of selective attention since the existing literature focuses heavily on dwell time and proportion of dwell time (Hogarth et al., 2008; Hogarth, Dickinson & Duka, 2010; Le Pelley et al., 2011; Le Pelley et al. 2013; Mitchell et al., 2012; Wills et al., 2007).

We also aimed to answer two questions that were more theoretically motivated. The first question was whether task learning and the acquisition of selective attention proceed at the same rate or whether one precedes the other. This is important because it is an assumption of explanations of the ORE. In the ORE individuals are trained beyond asymptote on Stage 1 of an IDS/EDS experiment. It has been reliably found that overtraining makes IDSs easier but EDSs more difficult. For example, Shepp and Turrisi (1969) found that when children with low IQ scores were overtrained by 0%, 100% or 300% in Stage 1, it made IDS progressively easier and EDS more difficult in Stage 2. This implies that attention varies even after the discrimination has been solved, otherwise there would be no change in performance when training past asymptote.

The second question was whether variations in eye gaze towards predictive and irrelevant stimuli were more immediately influenced by prediction error or prediction success. According to theories of learning and

attention that emphasise the role of surprise (e.g. Pearce & Hall, 1980), attention, and differences in attention depending on predictive validity, will be most pronounced following trials in which the discrepancy between expectation and trial outcome is maximized – that is to say, following errors. The current experiment examined this prediction of the Pearce-Hall model by presenting cue compounds (AV, AW, BV, BW, CX, CY, DX, DY) and establishing cues A, B, C and D as predictive of two outcomes and cues V, W, X and Y as irrelevant. We concurrently measured overt attention to predictive and irrelevant cues attracted using an eye-tracker.

2.1.1 **Methods**

2.1.1.1 ***Participants***

Sixteen postgraduate or undergraduate students from The University of Nottingham participated in return for a payment of £4 or £5. The sample consisted of 12 females (Mean ± SD: 22.3 ± 4.2). Exclusion criteria included not having normal or corrected-to-normal vision or visual disturbances triggered by flashing lights.

2.1.1.2 ***Apparatus and stimuli***

The experiment was designed and run using Experiment Builder. An SR (Mississauga, Canada) Research Eyelink 1000 eye-tracker sampled participant's right eye at a rate of 1000 Hz. Gaze location was determined by monitoring the location of the pupil using an infrared camera mounted on the desk in front of

the display monitor. A graphic series G90FB ViewSonic CRT monitor (44 × 44 cm) was used to display stimuli and screen resolution was set to 1026 × 768. Participants viewed stimuli binocularly from a distance of 56 cm; and head movements were minimised by the use of a desk-mounted chin and forehead rest. Thresholds used to define fixations and saccades were: 15° displacement, 30°/s velocity and 8,000°/s2 acceleration.

Stimuli serving as A, B, C, D, V, W, X and Y consisted of eight geometric patterns; each comprised equal numbers of black and white triangles to ensure identical luminance. Stimuli were 11 cm^2, and regions of interest (ROI) were set to this size, centred on the stimuli. The cues for each compound were presented 4 cm apart, in the centre horizontally of the screen with a white background. Stimuli subtended a visual angle of 11.25°^{2}. Stimuli that served as the predictive cues (A, B, C & D) were counterbalanced with the stimuli that served as the irrelevant cues (V, W, X & Y), as well as counterbalanced for side (see Appendix 1 for full counterbalancing). Compounds of two of these stimuli were paired with one of two outcomes (O1 = high pitched tone, 3000 Hz, 596 ms; O2 = low pitched tone, 300 Hz, 264 ms). Outcomes were heard via Hama HK-3031 Over-Ear Stereo Headphones. Participants made predictive responses using the key number 1 (high pitch) or number 2 (low pitch) button on the keyboard.

Table 2.1 *Experimental design for Experiment 1*

Compound	*Outcome*
AV	**O1**
AW	**O1**
BV	**O2**
BW	**O2**
CX	**O2**
CY	**O2**
DX	**O1**
DY	**O1**

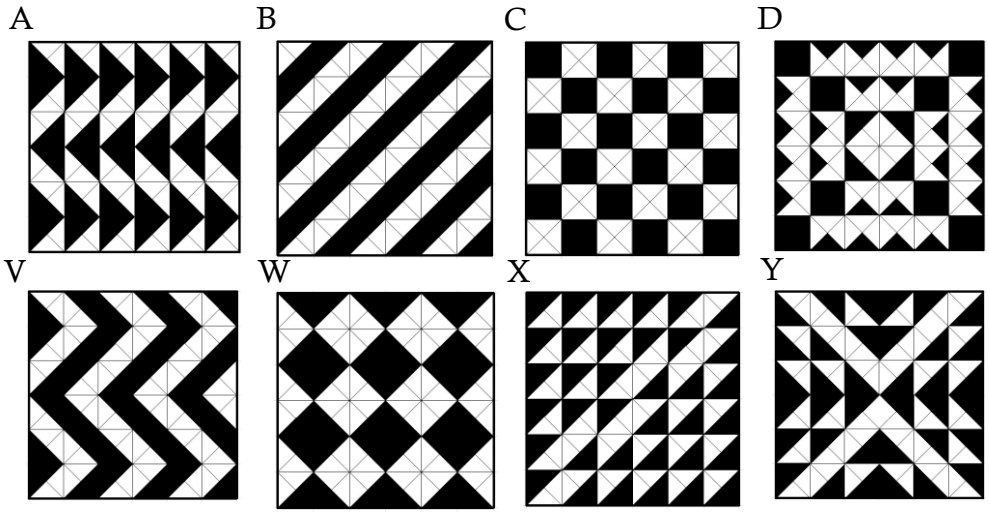


Figure 2.1 *Stimuli used in Experiment 1*

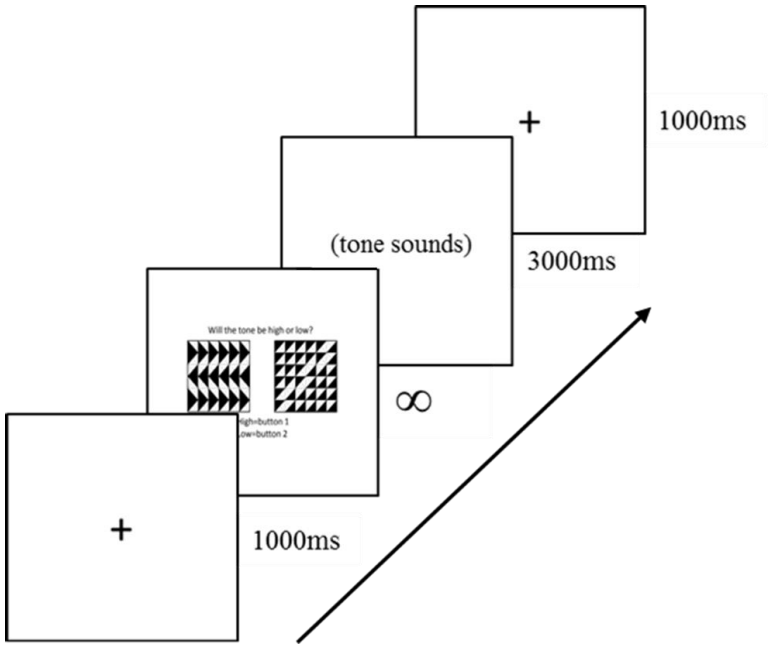


Figure 2.2 *Temporal layout of a trial during Experiment 1*

2.1.1.3 ***Procedure***

At the start of each experimental session, the experimenter checked that both pupil and corneal reflections were present whilst participants read on-screen instructions before performing a calibration. The eye-tracker was calibrated for each participant at the outset of the experimental session using a nine-point calibration, where a fixation point randomly appeared in one of nine positions. However, one participant could only be calibrated using a five-point procedure, where the extreme corners were omitted. A brief health questionnaire was administered on screen for exclusion criteria, written and verbal instructions were given and informed consent was gained. Written instructions: *"Each trial will begin with a fixation dot in the centre of the screen. You should look at each dot directly. Then, two pictures will appear and you will be asked 'Will the tone be high or*

low?' Press key number 1 if you think it will be high and 2 if you think it will be low. Please press the space bar to begin."

A fixation cross was first displayed in the centre of the screen for 1000 ms to ensure that participants' first fixation was not accidently in a ROI. This was replaced with the experimental stimuli, which remained on screen until participants made a valid response (number key 1 or 2) following which a blank screen appeared for 3000 ms whilst participants received audio feedback (high or low pitch tone). Trial order was randomised over the whole experiment. Participants were trained over 16 trial-blocks, within each block the eight compounds shown in Table 2.1 were presented twice, once with the predictive cue presented on the left, and once with the predictive cue presented on the right; consequently, the entire experiment consisted of 256 trials. Upon completion participants were thanked for their time and debriefed.

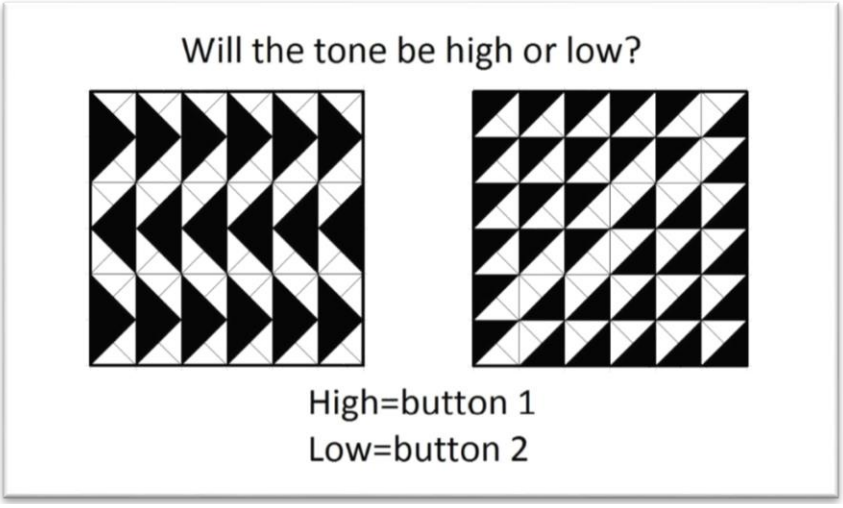


Figure 2.3 *Spatial layout of a trial during Experiment 1*

2.1.2 **Results**

Occasionally the eye-tracker was unable to track either the pupil, corneal reflections or both, this resulted in missing eye-movement data. To overcome this we imposed the same exclusion criteria used by Le Pelley et al. (2011). Participants were excluded from further analysis if the percentage of missing data >20% (zero participants were excluded) or if they achieved less than 60% correct responses across all trial blocks (three participants were excluded and replaced). For subsequent analysis Greenhouse-Geisser corrections were applied where sphericity was violated.

2.1.2.1 ***Behavioural data***

Figure 2.4a shows the mean proportion of correct responses collapsed across trial type across training. Mean accuracy reached over 90% by the final trial block which a one-sample t-test revealed was significantly above chance (50%), $t_{(15)} = 1500.50$, $p = .001$. A one-way repeated measures analysis of variance (ANOVA) of mean proportion correct with the factor of trial block (1-16) revealed a significant main effect, $F_{(3.78,56.76)} = 14.08$, $\eta_p^2 = .48$, $p < .001$, 95% CI [.26, .59]. Response times (RT) were also recorded during each trial block and Figure 2.4b shows that they reduced as training progressed. A one-way repeated measures ANOVA of RT with the factor of trial block (1-16) revealed a non-significant main effect, which approached significance, $F_{(1.34,20.02)} = 3.48$, $\eta_p^2 = .19$, $p = .06$, 95% CI [NA, .44].

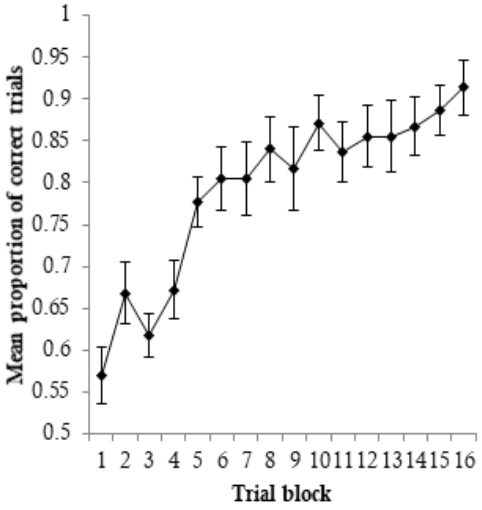


Figure 2.4a *Mean proportion of correct trials across trial blocks with within-subject error bars*

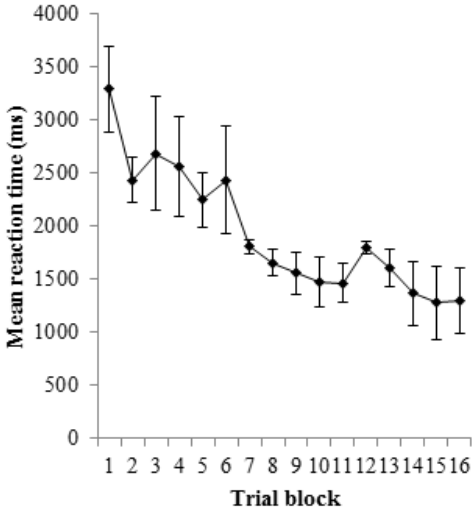


Figure 2.4b *Mean RT across trial blocks with within-subject error bars*

2.1.2.2 *Eye gaze analysis*

Figure 2.5a shows that the mean dwell time directed towards predictive and irrelevant stimuli decreased as training progressed, but dwell time was maintained at a higher level towards predictive cues. A two-way repeated measures ANOVA of mean dwell time with the factors of cue type (predictive vs. irrelevant) and trial block (1-16) revealed a significant main effect of cue type, $F_{(1,15)} = 4.56$, $\eta_p^2 = .23$, $p = .05$, 95% CI [NA, .51], non-significant main effect of trial block, $F_{(1.25,18.77)} = 3.22$, $\eta_p^2 = .18$, $p = .081$, 95% CI [NA, .43], and interaction, $F_{(4.47,67.06)} = 1.32$, $\eta_p^2 = .08$, $p = .268$, 95% CI [NA, .18].[1]

[1] A one-way repeated measures ANOVA of dwell time during O1 (high tone) trials with the factor of cue type (predictive vs. irrelevant) revealed a significant main effect, $F_{(1,15)} = 9.20$, $\eta_p^2 = .38$, p = .008. However, a one-way repeated measures ANOVA of dwell time during O2 (low tone) trials with the factor of cue type (predictive vs. irrelevant) revealed a non-significant main effect, $F_{(1,15)} = .60$, $\eta_p^2 = .04$, p = .451. One possible account for this disparity is that participants solve the discrimination on the basis of only half of the trials (O1) learning the specific contingency between the stimuli A and D and O1, and responding appropriately on these trials, and on any other trials in which these stimuli are not present, making the alternative response. This idea is

Cue presentation terminated when participants made a response and since RT reduced over training, this resulted in trials of differing lengths at different points during training. In an attempt to overcome this, eye gaze duration can be expressed as a proportion of trial duration by dividing dwell times for each stimulus type by RT. Figure 2.5b shows that the mean proportion of dwell time directed towards predictive cues was maintained over training, but the mean proportion of dwell time directed towards irrelevant cues steadily reduced. A two-way repeated measures ANOVA of mean proportion of dwell time with the factors of cue type (predictive vs. irrelevant) and trial block (1-16) revealed a significant main effect of cue type, $F_{(1,15)} = 12.31$, $\eta_p^2 = .45$, $p = .003$, 95% CI [.67, .66], trial block, $F_{(3.66,54.92)} = 3.04$, $\eta_p^2 = .16$, $p = .028$, 95% CI [NA, .30], and a significant interaction, $F_{(5.02,75.34)} = 2.73$, $\eta_p^2 = .15$, $p = .025$, 95% CI [NA, .26]. Simple main effects analysis of this interaction revealed a significant effect of cue type on trial blocks 2, 7, and then 10-16, smallest, $F_{(1,15)} = 5.35$,$\eta_p^2 = .26$, $p = .035$, 95% CI [NA, .53], with predictive cues always attracting a higher proportion of dwell time than irrelevant cues.[2]

supported by a one-way repeated measures ANOVA of accuracy with the factor of outcome type (O1 vs. O2) which revealed a significant main effect, $F_{(1,15)} = 6.82$, $\eta_p^2 = .31$, p = .020.

[2] A one-way repeated measures ANOVA of the proportion of dwell time during stimuli preceding O1 with the factor of cue type (predictive vs. irrelevant) revealed a significant main effect, $F_{(1,15)} = 12.38$, $\eta_p^2 = .45$, p = .003. An identical ANOVA conducted upon the proportion of dwell time during stimuli preceding O2 trials with the factor of cue type (predictive vs. irrelevant) revealed a non-significant main effect, $F_{(1,15)} = 3.09$, $\eta_p^2 = .17$, p = .099. This suggests that the main effect of cue type is driven by the O1 contingency and echoes findings reported in footnote 1.

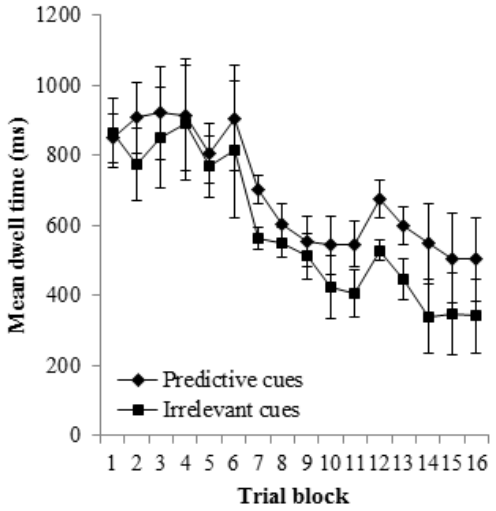


Figure 2.5a *Mean dwell time directed towards predictive and irrelevant cues across trial blocks within-subject error bars*

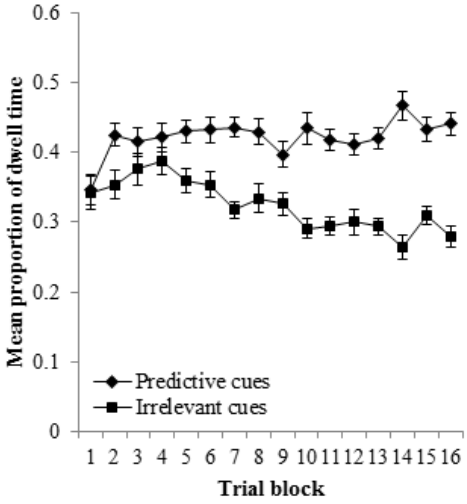


Figure 2.5b *Mean proportion of dwell time directed towards predictive and irrelevant cues across trial blocks within-subject error bars*

Figure 2.6a shows that the mean fixation count across trials decreased for predictive and irrelevant cues, but was maintained at a higher level for predictive cues, particularly during later training trials. However, a two-way repeated measures ANOVA of fixation count with the factors of cue type (predictive vs. irrelevant) and trial block (1-16) revealed a non-significant main effect of cue type, $F_{(1,15)} = 3.10$, $\eta_p^2 = .17$, $p = .099$, 95% CI [NA, .46], trial block, $F_{(1.24,18.54)} = 2.59$, $\eta_p^2 = .15$, $p = .119$, 95% CI [NA, .41], and a non-significant interaction, $F_{(4.20,62.97)} = 1.32$, $\eta_p^2 = .08$, $p = .272$, 95% CI [NA, .18].[3]

In keeping with the analysis performed upon the dwell time data, the mean proportion of fixation counts were also adjusted to take into account

[3] Similar to dwell time data, a one-way repeated measures ANOVA of fixation count during cues for O1 trials with the factor cue type (predictive vs. irrelevant) revealed a significant main effect, $F_{(1,15)} = 6.66$, $\eta_p^2 = .31$, $p = .021$. However, a one-way repeated measures ANOVA of fixation count during cues for O2 trials with the factor cue type (predictive vs. irrelevant) revealed a non-significant main effect, $F_{(1,15)} = .36$, $\eta_p^2 = .02$, $p = .559$.

differences in trial duration across training. Figure 2.6b shows that the proportion of fixation count is maintained towards predictive cues over training but decreases towards irrelevant cues. A two-way repeated measures ANOVA of mean proportion of fixation count with the factors of cue type (predictive vs. irrelevant) and trial block (1-16) revealed a main effect of cue type, $F_{(1,15)} = 7.91$, $\eta_p^2 = .35$, $p = .013$, 95% CI [.02, .60], trial block, $F_{(4.70,70.42)} = 9.63$, $\eta_p^2 = .39$, $p < .000$, 95% CI [.18, .50], and a significant interaction, $F_{(4.72,70.72)} = 2.61$, $\eta_p^2 = .15$, $p = .035$, 95% CI [NA, .25]. Simple main effects analysis of this interaction revealed a significant effect of cue type on trial blocks 2, 7, 10-11 and then 13-16, smallest, $F_{(1,15)} = 5.14$, $\eta_p^2 = .26$, $p = .039$, 95% CI [NA, .53], with predictive cues always attracting a higher proportion of fixations than irrelevant cues.[4]

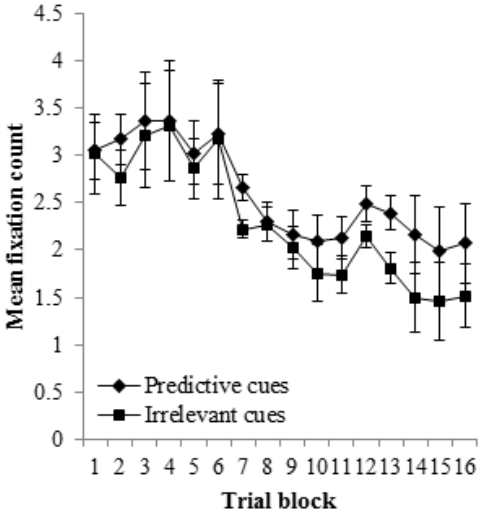


Figure 2.6a *Mean fixation count directed towards predictive and irrelevant cues across trial blocks within-subject error bars*

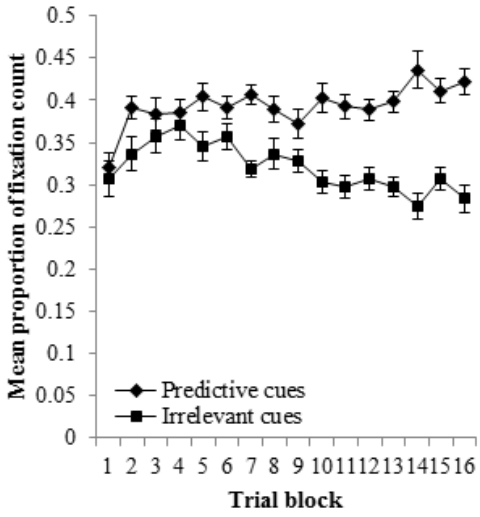


Figure 2.6b *Mean proportion of fixation count directed towards predictive and irrelevant cues across trial blocks within-subject error bars*

[4] Again, a one-way repeated measures ANOVA of the proportion of fixation count during O1 trials with the factor of cue type (predictive vs. irrelevant) revealed a significant main effect, $F_{(1,15)} = 9.38$, $\eta_p^2 = .39$, p = .008. A one-way repeated measures ANOVA of the proportion of fixation count during O2 trials with the factor of cue type (predictive vs. irrelevant) revealed a non-significant main, $F_{(1,15)} = 3.17$, $\eta_p^2 = .17$, p = .095.

Figure 2.7a shows the mean latency to make the first fixation towards predictive or irrelevant cues. A two-way repeated measures ANOVA of mean latency with the factors of cue type (predictive vs. irrelevant) and trial block (1-16) revealed a non-significant effect of cue type, $F_{(1,15)} = .37$, $\eta_p^2 = .02$, $p = .554$, 95% CI [NA, .28], a significant main effect of trial block, $F_{(3.87,58.04)} = 6.46$, $\eta_p^2 = .30$, $p < .001$, 95% CI [.08, .43], and a non-significant interaction, $F_{(4.50,67.49)} = .47$, $\eta_p^2 = .03$, $p = .777$, 95% CI [NA, .08].

Finally, Figure 2.7b shows that the mean number of trials per block in which the predictive cue or irrelevant cue attracted no fixations across training increases for irrelevant cues, but remains relatively low for predictive cues. A two-way repeated measures ANOVA of fixation omissions with the factors of cue type (predictive vs. irrelevant) and trial block (1-16) revealed a significant main effect of cue type, $F_{(1,15)} = 15.26$, $\eta_p^2 = .50$, $p = .001$, 95% CI [.66, .92], trial block, $F_{(3.80,57.14)} = 2.57$, $\eta_p^2 = .15$, $p = .05$, 95% CI [NA, .27], and a significant interaction, $F_{(5.32,79.74)} = 3.43$, $\eta_p^2 = .19$, $p = .006$, 95% CI [.02, .29]. Simple main effects analysis of this interaction revealed that cue type is significant on trial blocks 5, 7, and then 10-16, smallest, $F_{(1,15)} = 4.52$,$\eta_p^2 = .23$, $p = .050$, 95% CI [NA, .51], with more fixation omissions occurring for irrelevant cues than predictive cues.

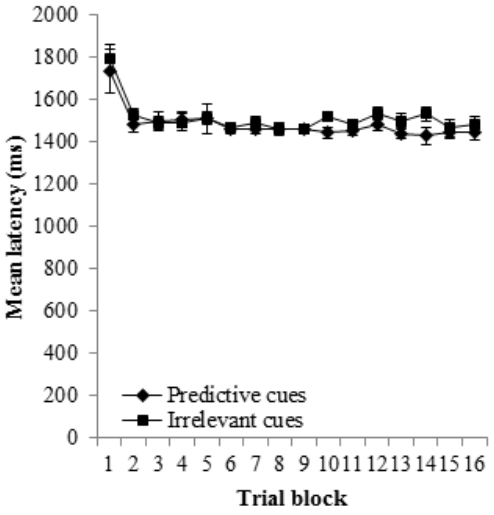


Figure 2.7a *Mean latency to first fixation towards predictive and irrelevant cues across trial blocks within-subject error bars*

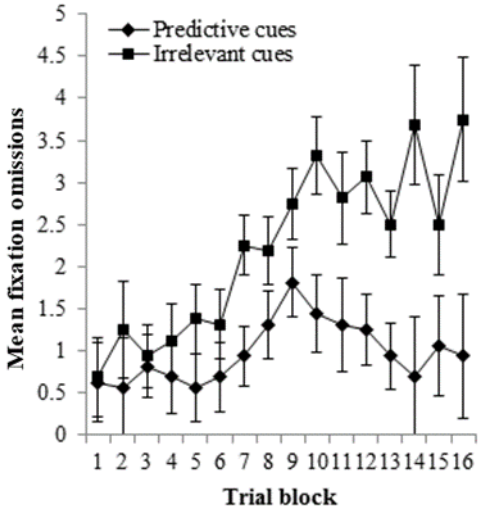


Figure 2.7b *Mean number of fixation omissions towards predictive and irrelevant cues across trial blocks within-subject error bars*

In order to determine whether different measures recorded by the eye-tracker were measuring a comparable underlying construct, correlation analysis was conducted. Normally distributed data (proportion of dwell time, proportion of fixation count & latency) were interpreted using Pearson's correlation coefficient. Data that were not normally distributed (dwell time & fixation count) was interpreted using Spearman's correlation coefficient. For predictive cues a strong positive correlation was revealed between dwell time and proportion of dwell time (r_s= .69, p = .003), fixation count (r_s= .95, p < .001) and proportion of fixation count (r_s= .67, p = .004). In addition to this, there was a strong positive correlation between proportion of dwell time and fixation count (r_s= .72, p = .002) and proportion of fixation count (r_s= .98, p < .001). There was also a strong positive correlation between fixation count and proportion of fixation count (r_s= .70, p = .002) (see Table 2.2a).

A similar pattern was revealed for irrelevant cues, a strong positive correlation was revealed between dwell time and proportion of dwell time (r_s= .82, p < .001), fixation count (r_s= .97, p < .001) and proportion of fixation count (r_s= .75, p = .001). In addition to this there was also a strong positive correlation between proportion of dwell time and fixation count (r_s= .81, p < .001) and proportion of fixation count (r_s= .96, p < .001). There was a strong positive correlation between fixation count and proportion of fixation count (r_s= .77, p < .001) (see Table 2.2b). In summary, the measures dwell time, proportion of dwell time, fixation count and proportion of fixation count were all highly correlated with each other, whereas the measures latency and latency omission were not strongly correlated with any other measures.

Table 2.2a *Correlations between measures of attention for predictive cues*

Predictive cues	*Dwell time*	*Proportion dwell*	*Fixation count*	*Proportion fixation*	*Latency*	*Latency omission*
Dwell time		0.691**	0.947**	0.674**	0.529*	0.244
Proportion dwell			0.715**	0.977**	0.109	0.046
Fixation count				0.703**	0.476	0.130
Proportion fixation					0.045	0.020
Latency						0.291
Latency omission						

* significant at .5 level, ** significant at .1 level

Table 2.2b *Correlations between measures of attention for irrelevant cues*

Irrelevant cues	*Dwell time*	*Proportion dwell*	*Fixation count*	*Proportion fixation*	*Latency*	*Latency omission*
Dwell time		0.818**	0.974**	0.750**	0.447	0.288
Proportion dwell			0.809**	0.955**	0.151	0.233
Fixation count				0.774**	0.547*	0.305
Proportion fixation					0.250	0.114
Latency						0.096
Latency omission						

2.1.2.1 ***Combined behavioural and eye gaze data***

In the following series of analysis, we attempted to answer the question, how is dwell time distributed on trials that are subsequently correct or incorrect? Behavioural and eye gaze data were combined to investigate the relationship between eye gaze and accuracy. Based on the high correlations observed between this dependent variable and others (e.g. fixation count), plus the widespread use of proportion of dwell time in the literature on learning and eye-tracking (see: Hogarth et al. 2008; Hogarth et al., 2009; Le Pelley et al., 2011; Le Pelley et al. 2013; Mitchell et al., 2012; Wills, Lavric, Croft & Hodgson, 2007), the analysis of the relationship between eye-tracking and behavioural data has been constrained to just this variable. Also, because there were more correct trials than incorrect, random correct trials were removed to equalise the number of these different trials types analysed for each participant. Figure 2.8a shows that on correct trials a higher mean proportion of dwell time was directed towards predictive cues compared to irrelevant cues. However, Figure 2.8b shows that on incorrect trials the relationship is noisy and no clear pattern

emerges. A three-way repeated measures ANOVA of proportion of dwell time with the factors of cue type (predictive vs. irrelevant), trial type (correct vs. incorrect) and trial block (1-16) revealed a non-significant main effect of cue type, $F_{(1,7)} = 1.32$, $\eta_p^2 = .16$, $p = .288$, 95% CI [NA, .53], trial type, $F_{(1,7)} = 2.22$, $\eta_p^2 = .24$, $p = .180$, 95% CI [NA, .58], trial block, $F_{(3,93)} = 1.19$, $\eta_p^2 = .15$, $p = .337$, 95% CI [NA, .11], but a significant interaction between cue type and trial type, $F_{(1,7)} = 9.10$, $\eta_p^2 = .57$, $p = .019$, 95% CI [.01, .77]. The remaining interactions were non-significant, largest, $F_{(4.35,30.42)} = 5.60$, $\eta_p^2 = .16$, $p = .532$, 95% CI [.10, .57]. Simple main effects analysis of the interaction between cue type and trial type revealed that participants only directed a differing amount of attention towards predictive and irrelevant cues on correct trials, $F_{(1,7)} = 19.94$, $\eta_p^2 = .74$, $p = .003$, 95% CI [.74, .66], with predictive cues always attracting a larger proportion of dwell time.

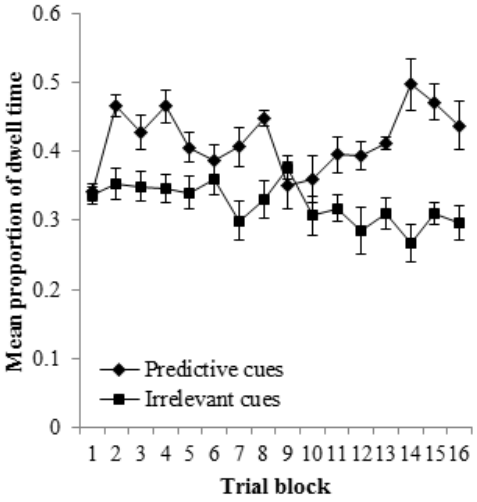


Figure 2.8a *Mean proportion of dwell time on correct trials across trial blocks within-subject error bars*

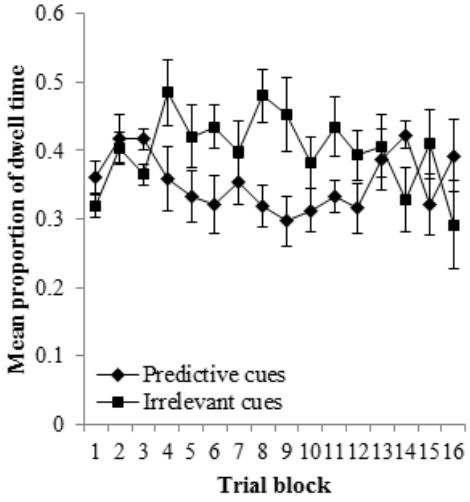


Figure 2.8b *Mean proportion of dwell time on incorrect trials across trial blocks within-subject error bars*

In the next analysis we attempted to answer the question, how does an error or correct response influence dwell times on the next same trial? Figure 2.9a shows that predictive cues attracted a higher proportion of dwell time compared to irrelevant cues when the outcome on trial 'n-1' (previous presentation of the same trial) had been predicted correctly. Figure 2.9b shows no difference in the proportion of dwell time directed towards predictive and irrelevant cues if the outcome prediction on trial 'n-1' was incorrect. A three-way repeated measures ANOVA of the proportion of dwell time with the factors of cue type (predictive vs. irrelevant), trial type (correct vs. incorrect) and trial block (1-16) revealed a significant main effect of cue type, $F_{(1,6)} = 14.40$, $\eta_p^2 = .71$, $p = .009$, 95% CI [.08, .84] and trial type, $F_{(1,6)} = 6.25$, $\eta_p^2 = .51$, $p = .047$, 95% CI [NA, .74], a non-significant main effect of trial block, $F_{(4.27, 25.64)} = 1.37$, $\eta_p^2 = .19$, $p = .270$, 95% CI [NA, .34], and a significant interaction between cue type and trial type, $F_{(1,6)} = 7.08$, $\eta_p^2 = .54$, $p = .037$, 95% CI [NA, .76]. The remaining interactions were non-significant, largest, $F_{(4.10,24.57)} = 1.14$, $\eta_p^2 = .16$, $p = .360$, 95% CI [NA, .31]. Simple main effects analysis of the interaction between cue type and trial type on n-1 correct trials revealed a significant effect of cue type on trial blocks 1,13 and 14, $F_{(1,6)} = 6.20$, $\eta_p^2 = .51$, $p = .047$, 95% CI [NA, .74], with predictive cues attracting a higher proportion of dwell time than irrelevant cues.

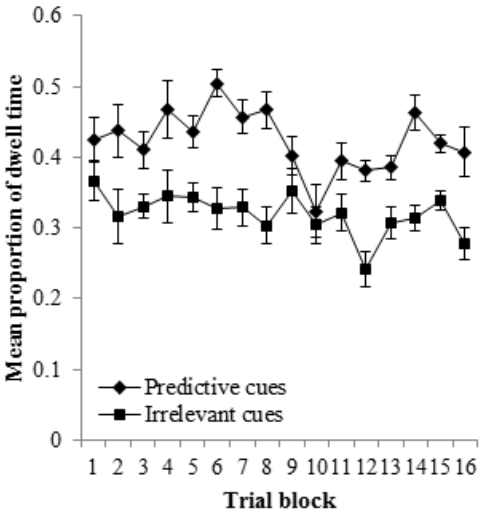


Figure 2.9a *Mean proportion of dwell time on correct n-1 trials across trial blocks within-subject error bars*

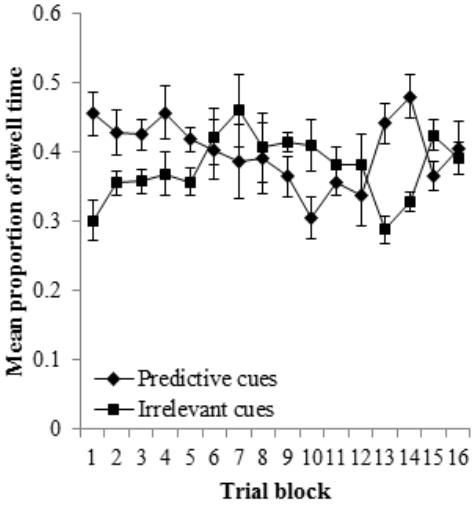


Figure 2.9b *Mean proportion of dwell time on incorrect n-1 trials across trial blocks within-subject error bars*

2.1.2.2 ***Learning rate versus overt attention***

The final analyses conducted addressed the question of whether acquisition of the task and the acquisition of selective attention proceeded at the same rate or whether one precedes the other. In order to examine this, the mean proportion of trials within each block that were correct were compared with the mean proportion of trials when the predictive cue attracted a higher proportion of dwell time (Figure 2.10a) or fixation counts (Figure 2.10b) than the irrelevant cue. All measures increased over training, but participants' solution of the task proceeded more rapidly than the differential distribution of proportion of dwell time/fixations. A two-way repeated measures ANOVA of proportion of dwell time with the factors of measure (attention vs. learning) and trial block (1-16) revealed a significant main effect of measure, $F_{(1,15)} = 52.48$, $\eta_p^2 = .78$, $p < .001$, 95% CI [.48, .86], trial block, $F_{(4.68,70.23)} = 7.91$, $\eta_p^2 = .35$, $p < .001$, 95% CI [.40,

.46], and a significant interaction, $F_{(7.28,109.20)} = 3.64$, $\eta_p^2 = .20$, $p = .001$, 95% CI [.04, .28]. Simple main effects analysis of the interaction between trials in which participants directed a greater proportion of dwell time towards the predictive cue and trial accuracy revealed a significant effect of measure from trial block 4 onwards, smallest, $F_{(1,15)} = 11.09$, $\eta_p^2 = .43$, $p = .005$, 95% CI [.67, .66], with trial accuracy (task learning) always being higher. A two-way repeated measures ANOVA of proportion of fixation count with the factors of measure (attention vs. learning) and trial block (1-16) revealed a significant main effect of measure, $F_{(1,15)} = 114.29$, $\eta_p^2 = .88$, $p < .001$, 95% CI [.89, .94], trial block, $F_{(5.12,76.84)} = 6.39$, $\eta_p^2 = .30$, $p < .001$, 95% CI [.00, .38], and a significant interaction, $F_{(15,255)} = 5.31$, $\eta_p^2 = .26$, $p < .001$, 95% CI [NA, .53]. Simple main effects analysis of the interaction between trials in which participants directed a greater proportion of fixation count towards the predictive cue and trial accuracy revealed a significant effect of measure from trial block 1 onwards, smallest, $F_{(1,15)} = 9.27$, $\eta_p^2 = .38$, $p = .008$, 95% CI [.08, .41], with trial accuracy (task learning) always being higher.

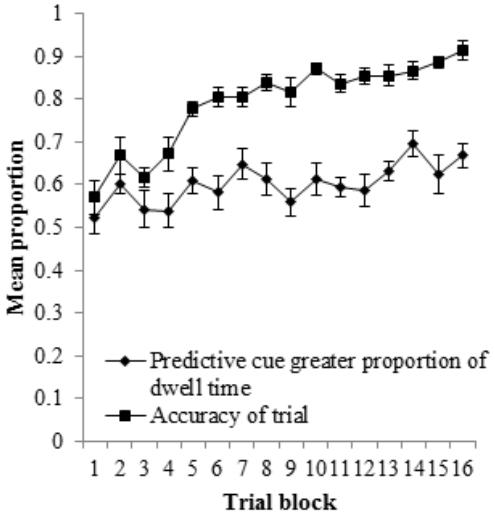


Figure 2.10a *Mean proportion of correct trials plotted against the mean proportion of trials in which the predictive cue received the greater proportion dwell time compared to irrelevant cue across trial blocks within-subject error bars*

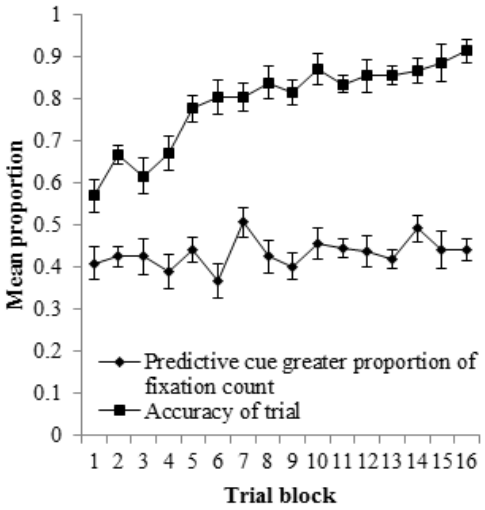


Figure 2.10b *Mean proportion of correct trials plotted against the mean proportion of trials in which the predictive cue received the greater proportion fixation count compared to irrelevant cue across trial blocks within-subject error bars*

2.1.3 Discussion

The purpose of Experiment 1 was to examine the properties of eye gazes directed towards predictive and irrelevant cues during a learned predictiveness task. The results revealed that participants differentially directed their eye gaze on the basis of a cues prior predictive history. Participants directed increased dwell time, proportion of dwell time, fixation count and proportion of fixation count towards predictive cues compared to irrelevant cues. It was also revealed that fixation omissions, where no attention was directed towards a cue, were more likely to happen for irrelevant cues as training progressed. However, no biases in eye gaze were observed when latency to first fixation was used as a measure of overt attention - the time taken to make the first fixation into predictive and irrelevant cues ROIs was the same. Furthermore, when the rate at which learning proceeded relative to the degree of attentional bias was compared, it was revealed that the former measure proceeded more rapidly than

the latter. A further analysis of these results revealed that eye gaze biases (as measured by proportion of dwell time were restricted to those trials that were a) correct and b) preceded by a correct trial.

A variety of measures revealed that the predictive validity of a cue influenced the amount of attention it attracted, particularly when the measure of eye gaze was normalised against the trial duration. These findings are in line with those from, for example, Stage 1 in Le Pelley et al. (2011) who also found that participants directed more attention towards cues that were established as predictive during a learned predictiveness task. These results are commonly interpreted as providing support for attentional models (e.g. Esber-Haselgrove, 2011; Le Pelley, 2004; Mackintosh; 1975) which state that attention will increase towards the cue which is the best available predictor of reinforcement, and decrease to those cues which are not. Although it should be noted that Figures 2.5a, 2.5b, 2.6a and 2.6b suggest that attention did not increase towards predictive cues, rather it was maintained at a higher level than irrelevant cues. Explanations for this could either be that Equation 1.4 ($\Delta \alpha > 1$ if $(\lambda - V_A < \lambda - V_X)$ is not applicable, which is rather extreme. Alternatively, we might propose that a parameter be used to determine the influence of gains and losses in attention, and that the weighting (i.e. influence) of Equation 1.4 is less than that for Equation 1.5. That is to say, learning to ignore stimuli progresses more rapidly than learning to attend to stimuli. Finally, it is possible that the stimuli entered the experiment with maximum levels of attention, with the consequence that measures of overt attention could only ever decrease. One possible way of combatting this issue would be to precede the training given in this experiment

with a manipulation to reduce overt attention to all of the cues, for example pre-exposure, or irrelevance training.

One reason for why we did not find evidence for differences in eye gaze when using latency to first fixation as a measure of attention could have been because the initial fixation into an ROI was not made based on the identity of the cue. Instead participants needed to foveate at the cues in order to identify whether they were predictive or irrelevant. Furthermore, participants often made their first fixation into the left ROI probably caused by the reading bias (Pollatsek, Bolozky, Well & Rayner, 1981). A further explanation could be that because the first fixation occurs at the outset of the trial, it is therefore temporally removed from feedback provided by the trial outcome and was consequently unmodified as training progressed (see: Reed & Reilly, 1990; Shanks, Pearson & Dickinson, 1989; Neunaber & Wasserman, 1986). However, the other measures of attention, in contrast, are sustained across the duration of the trial and may therefore be more contiguous with trial outcome. Although, it should be noted that eye-tracking is only able to measure overt attention even though it is commonly accepted that people are able to covertly shift their attention without moving their eyes (Posner, 1980).

The majority of the existing literature on attention within associative learning which use eye-tracking methodology have constrained their analysis to dwell time and proportion of dwell time (see: Hogarth et al., 2008; Hogarth et al., 2010; Le Pelley et al., 2011; Le Pelley et al. 2013; Mitchell et al., 2012, Wills et al., 2007). In the current experiment a range of attentional measures were recorded in order to determine whether all measures were equally representative of the learned predictiveness effect and selective attention more generally.

Echoing our previous results, it was found dwell time, proportion dwell time, fixation count and proportion fixation count were all highly correlated, implying that they measured the same underlying construct. However, latency to first fixation and fixation omission were not highly correlated with any of the measures of attention implying that in our experiment they were not able to tap into the same mechanism. Based on this finding, future analysis will be constrained to the proportion of dwell time as a measure of attention because it had the largest effect size of the measures which were highly correlated with each other.

By comparing gaze distribution and accuracy, we found that participants were more likely to make a correct prediction about the outcome of a trial if they looked more at the predictive cue compared to the irrelevant cue. This result predominantly serves as a "sanity check" for the current measures. If participants had spent relatively little time looking at the diagnostic feature of a stimulus on a given trial, then there is little reason to expect them to be correct on that trial. Of more theoretical interest, however, is the analysis that revealed that trial feedback influenced the distribution of attention on the subsequent trial with that compound. These results revealed that participants directed a larger proportion of dwell time towards the predictive cue compared to the irrelevant cue on; for example, trial AX when the outcome of the previous trial with AX was correctly predicted. However, when the outcome of the previous trial with AX was incorrectly predicted, the distribution of eye gaze was comparable between A and X. These results provide support for the model proposed by Mackintosh (1975) which claims that attention will increase to a cue if it has a relatively small prediction error – which is precisely the (local) situation that is

observed in this analysis. In contrast, these results are not in keeping with the spirit of the Pearce-Hall (1980) model. If attentional allocation was increased to stimuli that were followed by a greater, rather than a smaller prediction error, attention would have increased towards cues whose outcomes were unanticipated, i.e. the incorrect trials.

To answer the question whether attention and learning proceed at the same rate we compared mean accuracy with the mean number of trials when participants directed more attention (proportion of dwell time) towards the predictive cue than the irrelevant cue. It was found that both measures, task learning and acquisition of selective attention increased over training, however, learning increased at a faster rate. This is interesting because it implies that the transfer of the learning mechanism to the attentional mechanism is not perfect. It also provides an explanation for the finding by Shepp and Turasi (1969) that EDSs become easier if the first discrimination has been overtrained. Based on our finding, it could be suggested that during a normal IDS/EDS experiment although learning has reached asymptote, attentional change lags behind so when the first discrimination is overtrained it gives attention time to catch up – therefore making the shift easier. The purpose of this lag in attention might be to keep learning conservative because attributing high levels of salience to a cue for which only limited information has been acquired might be disadvantageous. For example, if the alternative situation were true – that is to say attention exceeded associative strength or prediction error, (e.g. the output from the learning system was amplified before feeding into attention) it would become abnormally sensitive to spurious correlations. This might be what happens in disorders such as schizophrenia. Kapur, Mizrahi and Li (2005) argue that

psychosis results from abnormally high salience being attached to irrelevant events. As Haselgrove et al. (2016) note, this may be the mechanism that underpins the abnormally high salience that irrelevant events attracted in schizophrenia.

2.2 Experiment 2

The support that Experiment 1 and others (e.g. Beesley et al., 2015; Le Pelley et al., 2011; Le Pelley et al., 2013; Mitchell et al., 2012) provide for the Mackintosh (1975) model is partly eroded by Hogarth et al. (2008) who, using a similar experimental design, found that more attention was directed towards partially predictive cues compared to fully predictive cues. This provides support for Pearce-Hall's (1980) model of associative learning which claims that attention is guided by uncertainty, not predictiveness.

In Hogarth et al.'s (2008) design the compound A and X was always followed by an outcome (AX+), compound C and X was always followed by the omission of an outcome (CX-), and compound B and X was followed by an outcome on 50% of the trials but an omission on the other 50% of the trials (BX+/-). Hogarth et al. compared the amount of dwell time that participants spent exploring the 'unique' cue (A, B or C), with the amount of dwell time that participants directed towards the 'common' cue (X). They found that 'contingency-aware' participants directed more dwell time towards cue B than X, compared to the difference in dwell time directed towards cues A vs X and C vs X which were perfectly predictive of the outcome. These results can be explained using the Pearce-Hall (1980) model because it grants preferential attention towards cues followed by surprising outcomes – which will always be the case on trials with BX.

The findings obtained by Hogarth et al. (2008) are important because they provide almost unique support for the Pearce-Hall (1980) effect in humans.

Therefore, the aim of Experiment 2 was to replicate their findings using the same experimental stimuli and a comparable procedure to Experiment 1.

2.2.1 **Methods**

2.2.1.1 ***Participants***

Sixteen undergraduate students from The University of Nottingham participated in return for course credit or a payment of £3. The sample consisted of 14 females (Mean ± SD: 21 ± 1.85). Exclusion criteria were the same as Experiment 1.

2.2.1.2 ***Apparatus and stimuli***

Experiment 2 was designed and run using Experiment Builder. A SR (Mississauga, Canada) Research Eyelink 1000 Plus eye-tracker sampled participant's right eye at a rate of 1000 Hz. Participants viewed stimuli binocularly from a distance of 67 cm; their head movements were minimised by the use of a chin and forehead rest. The screen was 33 × 57 cm, BenQ XL2420T LED monitor with resolution set to 1920 × 1080 at 114 Hz. Thresholds used to define fixations and saccades were: 15° displacement, 30°/s velocity and 8,000°/s2 acceleration.

Stimuli consisted of eight geometric patterns, the same ones used in Experiment 1. The tone 50 db, 554 Hz (C-sharp) with a graduated rise time was heard via Sony MDR-ZX100 Over-Ear Stereo Headphones. Stimuli were 10.5 cm^2, and regions of interest (ROI) were set to this size. The cues in each

compound were presented 10 cm apart, in the centre of the screen with a white background. Between the stimuli were the words: "*How likely is the noise? 1, 2, 3, 4, 5, 6, 7, 8, 9, 10*" with "*Unlikely*" underneath the number 1 and "*Likely*" underneath the number 10. Stimuli subtended a visual angle of 8.98°. Stimuli were randomly assigned to serve as stimuli A, B, C, X (see Table 2.3, and Appendix 2 for full counterbalancing). Cue A served as a perfect predictor that the tone would occur. Cue C served as a perfect predictor that the tone would not occur. Cue B was an uncertain predictor whether the tone would occur because it was present on half of the trials and absent on the remainder. Finally, cue X occurred on all trials and was therefore irrelevant for predicting the tone's occurrence. Participants made their response using the buttons: 1, 2, 3, 4, 5, 6, 7, 8, 9 and 0 (that had a sticker with the number 10 over it) on the keyboard.

Table 2.3 *Experimental design for Experiment 2*

Compound	***Probability of tone***
AX	**1**
BX	**0.5**
CX	**0**
XA	**1**
XB	**0.5**
XC	**0**

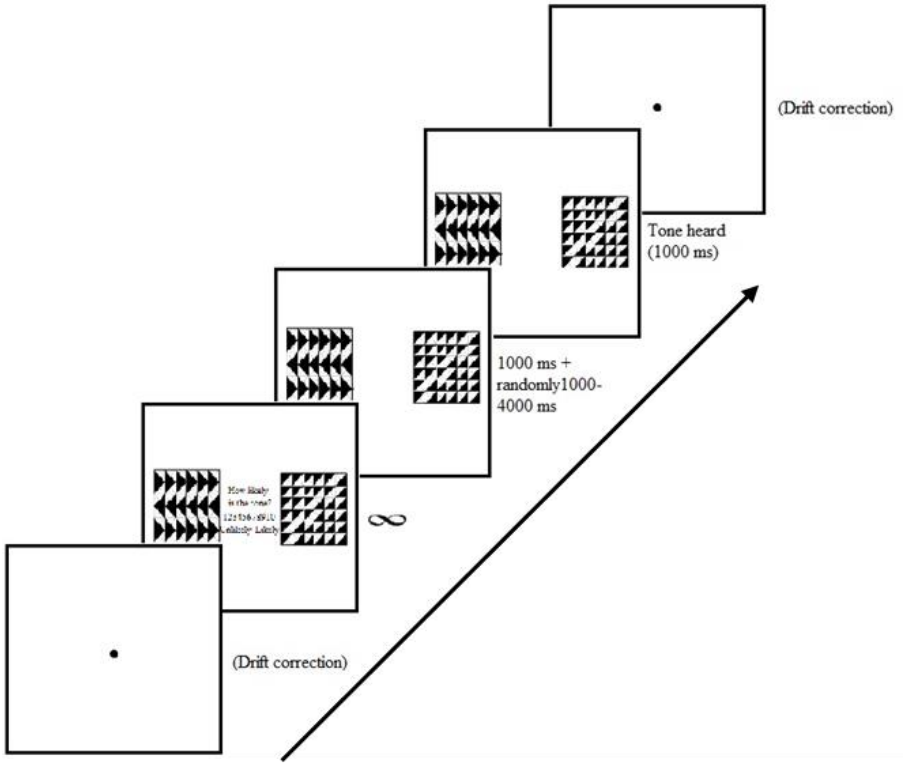


Figure 2.11 *Temporal layout of a trial during Experiment 2*

2.2.1.3 ***Procedure***

The eye-tracker was calibrated for each participant at the outset of the experimental session using a nine-point calibration, except for one participant who could only be calibrated using a five-point procedure.

A brief health questionnaire was administered to screen for exclusion criteria, written instructions and verbal instructions were given and informed consent was gained. Written instructions said: "*Thank you for participating in this study. Your first task is to focus on the dot and follow it with your eyes. Press the space bar to begin the experiment*." "*Each trial will begin with a fixation dot in the centre of the screen. You should look at each dot directly. Then two pictures will appear and you will be asked how likely it is that a noise will occur subsequently. Please rate the likelihood of the*

noise on a scale of 1-10, where 1=unlikely and 10=likely. Please press the space bar to begin."

At the start of each experimental session, the experimenter checked that both pupil and corneal reflections were present whilst participants read on-screen instructions before performing a calibration. The experiment was self-paced to replicate the methodology used in Hogarth et al. (2008). The question disappeared upon response but the stimuli remained on screen for 1000 ms after. If the trial was a reinforced, then the tone would occur randomly between 1000 ms to 4000 ms after that. This meant that trials differed in length between 1000 ms to 5000 ms after participants made an appropriate key response. The tone sounded for 1000 ms and on no tone trials a silence period occurred for the equivalent length of time.

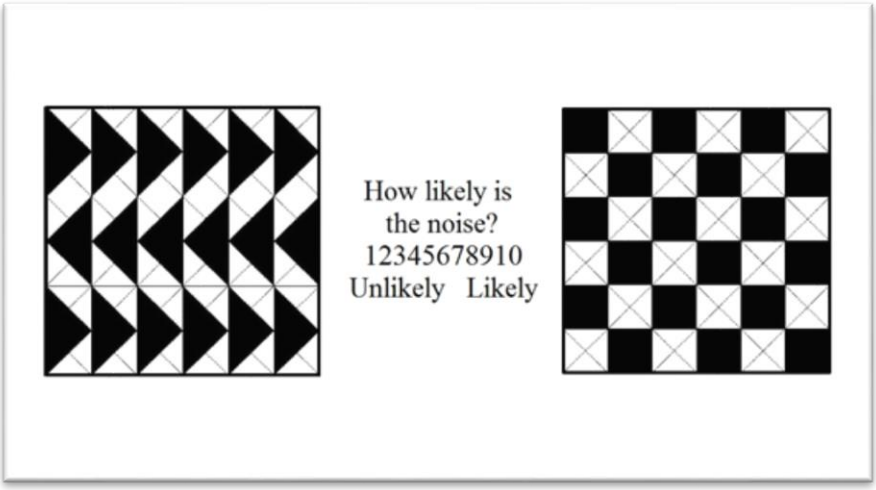


Figure 2.12 *Spatial layout of a trial during Experiment 2*

Participants were trained over 8 trial blocks, with AX, BX and CX compounds presented 6 times in each trial block. In total, each compound was

presented 48 times, with each cue presented an equal number of times on the left and right-hand side of the screen; consequently, the entire experiment consisted of 144 trials. Trial order was block randomised over the whole experiment. After participants had responded using the numbers, the compound stimulus remained on the screen whilst they received audio feedback (tone or no tone) so participants knew whether their prediction was correct or incorrect. Upon completion participants were thanked for their time and debriefed.

2.2.2 **Results**

Using the same criteria as Hogarth et al. (2008), all participants were contingency aware because they gave predictive no tone cues the lowest expectancy rating, followed by the predictive 50% tone cues, and gave predictive tone cues the highest expectancy rating.

2.2.2.1 ***Behavioural data***

Figure 2.13a reveals that the time taken to respond decreased over training. A two-way repeated measures ANOVA of RT with the factors of trial type (tone, 50% tone & no tone) and trial block (1-8) revealed a significant main effect of trial block, $F_{(3.39,50.82)} = 33.94$, $\eta_p^2 = .69$, $p < .001$, 95% CI [.52, .77], a trend-level main effect of trial type, $F_{(2,30)} = 3.12$, $\eta_p^2 = .18$, $p = .059$, 95% CI [NA, .37, and a non-significant interaction, $F_{(14,210)} = .62$, $\eta_p^2 = .04$, $p = .851$, 95% CI [NA, .03].

The mean expectancy rating on each trial block is shown in Figure 2.13b. A two-way repeated measures ANOVA of expectancy rating with the factors of

trial type (predictive tone, predictive 50% tone & predictive no tone) and trial block (1-8) revealed a significant main effect of trial type, $F_{(1.25,18.69)} = 59.76$, $\eta_p^2 = .80$, $p < .001$, 95% CI [.56, .87], a non-significant main effect of trial block, $F_{(7,105)} = 1.53$, $\eta_p^2 = .09$, $p = .165$, 95% CI [NA, .15], and a significant interaction, $F_{(5.28,79.20)} = 6.86$, $\eta_p^2 = .31$, $p < .001$, 95% CI [.12, .42]. Simple main effects analysis of this interaction revealed a significant difference between predictive no tone and predictive tone cues from trial block 1 onwards, smallest, $F_{(5.28,79.20)} = 3.65$, $\eta_p^2 = .74$, $p = .001$, 95% CI [.01, .18]. There was also a significant difference between predictive no tone and predictive 50% tone cues in all trial blocks, except block 5, smallest, $F_{(5.28,79.20)} = 2.66$, $\eta_p^2 = .67$, $p = .007$, 95% CI [NA, .38]. Finally, there was a significant difference between predictive tone and predictive 50% tone cues from trial blocks 2 onwards, smallest, $F_{(5.28,79.20)} = 3.20$, $\eta_p^2 = .71$, $p = .003$, 95% CI [NA, .45].

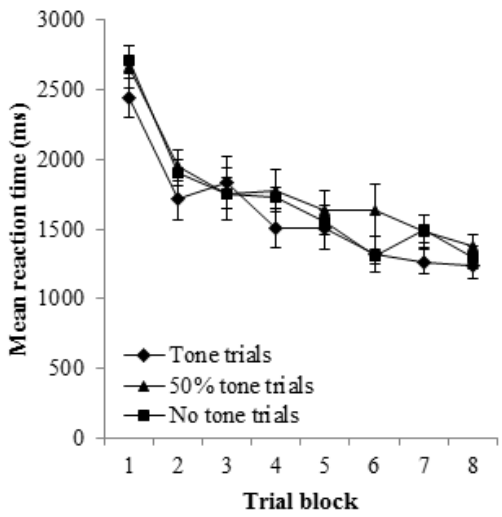


Figure 2.13a *Mean reaction time for tone, 50% tone and no tone trials across trial blocks within-subject error bars*

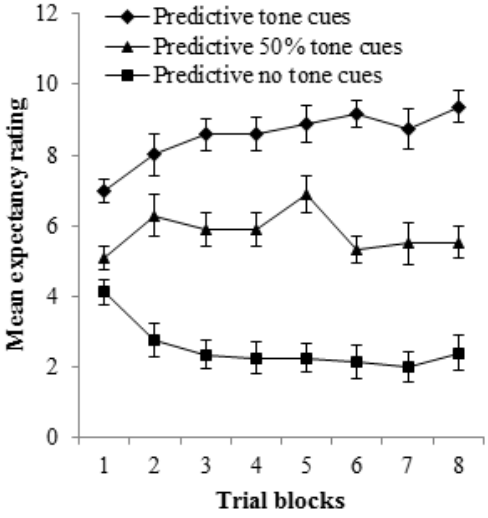


Figure 2.13b *Mean expectancy rating for the predictive cue on tone, 50% tone and no tone trials across trial blocks within-subject error bars*

The expectancy data replicates Hogarth et al. (2008), however, they log transformed their RT data and found that participants took longer to make a response on 50% tone trials. Therefore, we also log transformed our RT data and performed a two-way repeated measures ANOVA with the factors of trial type (tone, 50% tone & no tone) and trial block (1-8) which revealed a significant main effect of trial block, $F_{(3.73,55.89)} = 31.76$, $\eta_p^2 = .68$, $p < .001$, 95% CI [.03, .19], a trend-level main effect of trial type, $F_{(1.32,19.82)} = 3.72$, $\eta_p^2 = .20$, $p = .058$, 95% CI [.04, .15], and a non-significant interaction, $F_{(14,210)} = .797$, $\eta_p^2 = .05$, $p = .671$, 95% CI [NA, .07].

2.2.2.2 *Eye gaze analysis*

Based on the findings of Experiment 1, we constrained our analysis to the proportion of dwell time because it demonstrated the largest effect which closely correlated with other measures. To provide a better comparison to Hogarth et al. (2008) we replicated their methodology and investigated eye gaze during the first five seconds of a trial. Also, to provide a better comparison to Experiment 1, we analysed eye gaze until participants made a trial response.

FIRST FIVE SECONDS

Figure 2.14 shows that the predictive 100% (AX+) and predictive 50% (BX+/-) cues attract a larger proportion of dwell time compared to predictive 0% (CX-) cues during the first five seconds of a trial. A two-way repeated measures ANOVA of proportion of dwell time with the factors of cue type (predictive vs. irrelevant) and trial type (+, +/- & -) revealed a significant main effect of cue

type, $F_{(1,15)}$ = 7.04, η_p^2 = .32, p = .018, , 95% CI [.03, .47] a non-significant main effect of trial type, $F_{(2,30)}$ = .78, η_p^2 = .50, p = .470, 95% CI [NA, .17], and a significant interaction, $F_{(2,30)}$ = 3.51, η_p^2 = .19, p = .043, 95% CI [NA, .03]. Simple main effects analysis of the interaction revealed a significant effect of cue type on + trials and +/- tone trials only, smallest, $F_{(1,15)}$ = 5.97, η_p^2 = .29, p = .027, 95% CI [.66, .92], with predictive cues always attracting a higher proportion of dwell time than irrelevant cues on these trials.

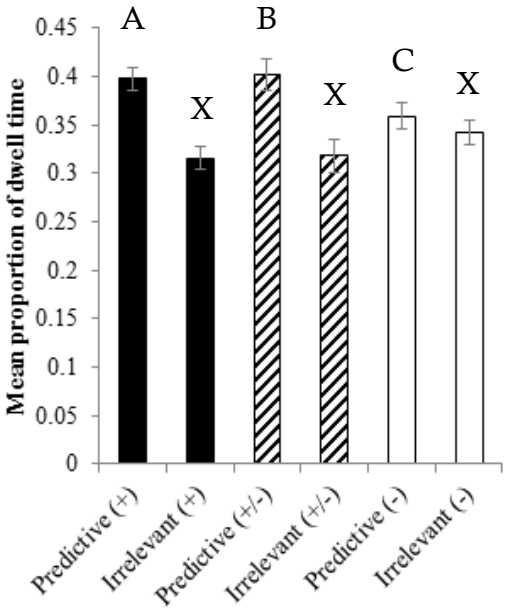


Figure 2.14 *Mean proportion of dwell time directed towards predictive and irrelevant cues on tone, 50% tone and no tone trials in the first five seconds of a trial*

TIME UNTIL RESPONSE

Figure 2.15 shows that predictive cues attracted a larger proportion of dwell time compared to irrelevant cues during the period between the onset of the trial and the time at which participants made a response. A two-way

repeated measures ANOVA of proportion of dwell time with the factors of cue type (predictive vs. irrelevant) and trial type (+, +/- and -) revealed a significant main effect of cue type, $F_{(1,15)} = 7.96$, $\eta_p^2 = .35$, $p = .013$, 95% CI [.05, .52], a non-significant main effect of trial type, $F_{(2,30)} = 2.59$, $\eta_p^2 = .15$, $p = .091$, 95% CI [.03, .39], and a non-significant interaction, $F_{(2,30)} = 2.45$, $\eta_p^2 = .14$, $p = .103$, 95% CI [NA, .03].

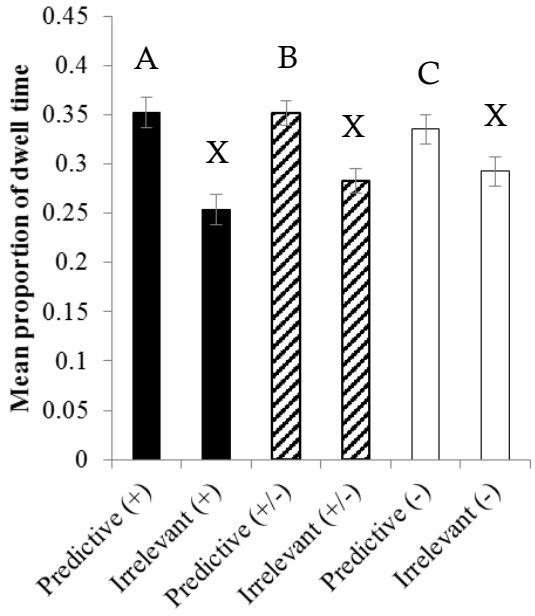


Figure 2.15 *Mean dwell time directed towards predictive and irrelevant cues on tone, 50% tone and no tone trials until participants made a trial response*

2.2.3 **Discussion**

Using the same experimental design and a similar methodology to that employed by Hogarth et al. (2008), Experiment 2 revealed that more attention was directed towards predictive cues compared to irrelevant cues which replicates and extends the generality of Experiment 1. However, the pattern of

results for BX trials was diametrically opposed to those obtained by Hogarth et al.

Expectancy ratings for cues that were predictive of the tone (+) increased, whilst expectancy ratings for cues that were predictive of no tone (-) decreased, and expectancy ratings for cues that were partially predictive of the tone (+/-) remained stable over the course of experiment. In addition, RT for all trial types steadily decreased across trial blocks.

In keeping with the study conducted by Hogarth et al. (2008), eye gaze was measured during the first five seconds of each trial over the course of the experiment. In addition, to provide a better comparison to Experiment 1 of the current thesis, eye gaze was also measured between the onset of the trial to the point at which participants made a response. Results revealed that at a within-trial-level a larger proportion of dwell time was directed towards predictive cues compared to irrelevant cues, as observed in Experiment 1 and Hogarth et al. (2008; see also Hogarth, Dickinson and Duka, 2010). This finding provides support for the Mackintosh (1975) model of associative learning which predicts enhanced attention towards the best available predictor of reinforcement.

However, Experiment 2 also revealed that the difference in dwell time observed between cues B and X was not observed on trials with cues C and X. The Mackintosh (1975) model struggles to explain this particular feature of the current experiment since it predicts that more attention should have been directed towards the cue that was established as a good predictor of the absence of the outcome compared to a cue that was followed by an outcome on half the trials and not on the remaining trials. To some degree this supports the Pearce-

Hall (1980) model of associative learning because it predicts that cues that are partially reinforced will receive enhanced attention, despite being an uncertain predictor of the outcome compared to cues that predict the outcome with complete certainty. However, it could simply have been that as learning is commonly thought of as proceeding slower on no-outcome trials, learning about the CX relationship had not reached asymptote and if we had included more trials the same effect would have been observed.

To summarise, the results of Experiment 2 replicate those observed in Experiment 1; however, there are some inconsistencies which might suggest that a cue associated with uncertainty attracts more attention than one that is predictive. Taken at face value, these findings imply that neither the Pearce-Hall (1980) model nor the Mackintosh (1975) model can fully accommodate all of Experiment 2's findings.

2.3 Experiment 3

When analysing the literature that provides support for the Pearce-Hall (1980) model of associative learning, it becomes clear that included in the experimental design is a degree of uncertainty. That is, a cue that is not either 100% predictive or 100% irrelevant (see: Hogarth et al., 2008; Hogarth, Dickinson & Duka, 2010; Griffiths & Mitchell, 2008). The study by Hogarth et al. (2008) also had the additional problem that since the irrelevant cue X was presented on every trial, it was more familiar and therefore less novel than other cues. However, to date, only a handful of studies have manipulated the predictive validity of the predictive cue so as to render it an imperfect predictor of reinforcement. Therefore, it is important to investigate attention under conditions of increased uncertainty if we are to fully understand the role of attention in learning.

A study by Beesley et al. (2015, also see Luque, Vadillo, Le Pelley & Beesley, 2017) attempted to address this issue by recording eye movements during a contingency learning task under conditions of 100% certainty and 70% certainty. During Experiment 1, participants were presented with cue compounds (fictitious molecules), AW, AX, BW, BX, CY, CZ, DY, DZ, and asked to predict whether O1 or O2 (different types of mutant) would follow. Cues A and B were established as 100% predictive of the outcome, whilst cues W and X were established as irrelevant for predicting the outcome of a trial. However, cues C and D were only established as 70% predictive of the outcome and cues Z and Y, like W and X, were established as irrelevant for predicting the outcome of a trial (see Table 2.4).

Table 2.4 *Experimental design for Beesley et al. (2015)*

Compound	*P(O1)*	*P(O2)*
AW	**1**	**0**
AX	**1**	**0**
BW	**0**	**1**
BX	**0**	**1**
CY	**.7**	**.3**
CZ	**.7**	**.3**
DY	**.3**	**.7**
DZ	**.3**	**.7**

Interestingly, their results showed that the dwell times on trials with C and D were overall longer than dwell times on trials with A and B. This finding provides support for the Pearce-Hall (1980) model of associative learning, and echoes the findings of Hogarth et al (2008). In addition, like the current Experiment 1 and 2, at a within-trial-level Beesley et al. (2015) found that dwell time was longer towards predictive cues compared to irrelevant cues on both certain and uncertain trials – a result that is more in keeping with the predictions of the model proposed by Mackintosh (1975). Together, Beesley et al. argue that these results are evidence for two mechanisms of attention. One mechanism that is explorative and functions using a Pearce-Hall-type mechanism to direct attention towards cues that precede events which cannot be predicted with any certainty in order to promote more learning. The other mechanism is exploitative and functions using a Mackintosh-type mechanism in order to bias attention towards cues which have been established as most predictive of an event.

The aim of Experiment 3 was to measure overt visual attentional distribution in cases of high and low certainty in an attempt to replicate Beesley et al.'s (2015) findings. Also, given the partial success we had in replicating the results of Hogarth et al (2008) in Experiment 2, it is important to determine whether other results that have been taken to support the operation of a Pearce-Hall (1980) mechanism in humans can be replicated.

2.3.1 **Methods**

2.3.1.1 ***Participants***

Thirty-eight postgraduate or undergraduate students from The University of Nottingham participated in return for payment of £3 or course credit. The sample consisted of 28 females (Mean ± SD: 20.64 ± 2.68). Exclusion criteria were the same as in previous experiments.

2.3.1.2 ***Apparatus and stimuli***

The apparatus and stimuli were identical to that used in Experiment 1. In the certain condition, cues A and B were established as 100% predictive of either O1 or O2 (high or low-pitched tone), while cues V and W were established as irrelevant for predicting the outcome of a trial. In the uncertain condition cues C and D were established as 75% predictive of either O1 or O2, while cues X and Y were established as irrelevant for predicting the outcome of a trial. For half of the participants, stimuli in the certain condition were coloured red and stimuli in the uncertain condition were coloured black, the other half of participants

received the opposite pattern of stimulus assignment (see Table 2.5, and Appendix 3 for full counterbalancing). Compounds were presented twice within each trial block, once with the predictive cue appearing on the left-hand side of the display, and once on the right; the experiment consisted of 16 trial blocks with 256 trials in total.

Table 2.5 *Experimental design for Experiment 3*

Compound	*Probability of O1*	*Probability of O2*
AV	**1**	**0**
AW	**1**	**0**
BV	**0**	**1**
BW	**0**	**1**
CX	**0.25**	**0.75**
CY	**0.25**	**0.75**
DX	**0.75**	**0.25**
DY	**0.75**	**0.25**

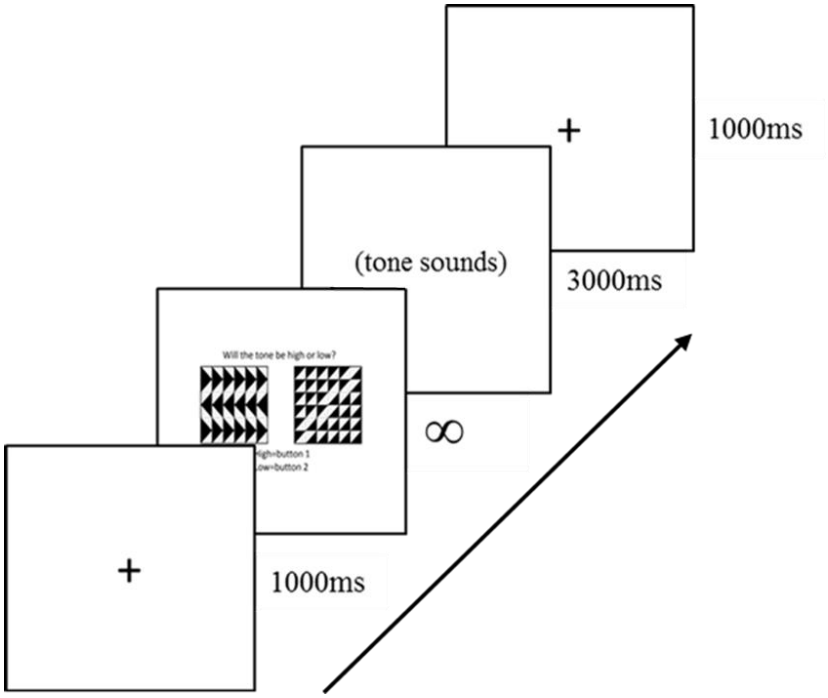


Figure 2.16 *Temporal layout of a trial during Experiment 3*

2.3.1.3 ***Procedure***

The procedure was identical to that employed in Experiment 1. The eye-tracker was calibrated using a nine-point procedure for 34 participants, and a five-point procedure for four participants.

2.3.2 **Results**

Based on results obtained in a pilot study we relaxed the exclusion criteria imposed in Experiment 1. Regardless of this, only one participant fell below 60% accuracy (57%) over training on the certain trials. We also relaxed the missing data exclusion criteria as three participants had over 20% missing data, the greatest being 23%. We did however exclude three participants where

the eye-tracker lost the eye for ten or more consecutive trials. Finally, two additional participants were excluded from analysis due to researcher error. For subsequent analysis Greenhouse-Geisser corrections were applied where sphericity was violated.

2.3.2.1 *Behavioural data*

Figure 2.17a shows that the mean proportion of accurate trials increased across training on trials that were both perfectly predictive of the trial outcome and those that were partially predictive. Also, unsurprisingly, participants were better able to learn the predictive contingencies during the certain condition. By trial block 16 in the certain condition the mean accuracy was 77.91%, which a one-sample t-test reported as significantly above chance (50%), $t_{(31)} = 1090.77$, $p < .001$. A one-sample t-test was also performed on trial block 16 in the uncertain condition where the mean percent correct was 54.03%, which was also found to be significantly above chance (37.5%, half of 75%), $t_{(31)} = 1710.61$, $p < .001$. A two-way repeated measures ANOVA with the factors of trial type (certain vs. uncertain) and trial block (1-16) revealed a significant main effect of trial type, $F_{(1,31)} = 27.57$, $\eta_p^2 = .47$, $p < .001$, 95% CI [.20, .68], and trial block, $F_{(15,465)} = 3.77$, $\eta_p^2 = .11$, $p < .001$, 95% CI [.04, .14], but a non-significant interaction, $F_{(15,465)} = 1.28$, $\eta_p^2 = .04$, $p = .208$, 95% CI [NA, .05].

Figure 2.17b shows that the mean RT for both certain and uncertain conditions decreased over training; however, RTs on certain trials were shorter. These observations were confirmed by a two-way repeated measures ANOVA of RT with the factors of trial type (certain vs. uncertain) and trial block (1-16).

This analysis revealed a significant main effect of trial type, $F_{(1,31)} = 12.70$, $\eta_p^2 = .29$, $p = .001$, 95% CI [.06, .50], and trial block, $F_{(3.26,101.01)} = 8.63$, $\eta_p^2 = .22$, $p < .001$, 95% CI [.07, .33], but a non-significant interaction, $F_{(6.63,205.44)} = 1.18$, $\eta_p^2 = .04$, $p = .320$, 95% CI [NA, .07]. Again, this demonstrates that RT did not improve at the expense of accuracy (speed accuracy trade-off).

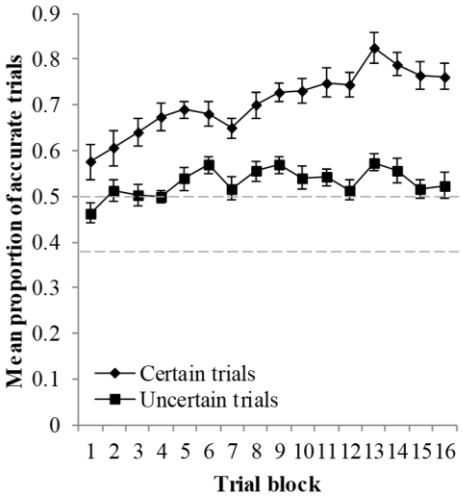


Figure 2.17a *Mean proportion of correct trials for certain and uncertain conditions across trial blocks*

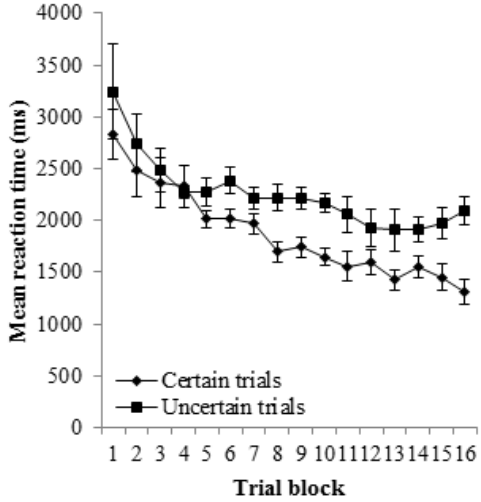


Figure 2.17b *Mean reaction time for certain and uncertain conditions across trial blocks*

2.3.2.2 *Eye gaze analysis*

Figure 2.18a shows the mean proportion of dwell time that was directed towards the two ROIs together on uncertain trials compared with certain trials. Overall, dwell times were longer on uncertain trials than certain trials. This impression was confirmed with a one-way repeated measures ANOVA with the factor trial type (certain vs. uncertain) revealed a significant main effect, $F_{(1,31)} = 9.14$, $\eta_p^2 = .23$, $p = .005$, 95% CI [.06, .28]. Figure 2.18b shows that, at a within

trial level, a larger proportion of dwell time was directed towards predictive cues compared to irrelevant cues in both certain and uncertain conditions. A two-way repeated measures ANOVA with the factors of trial type (certain vs. uncertain) and cue type (predictive vs. irrelevant) revealed a significant main effect of trial type, $F_{(1,15)} = 9.45$, $\eta_p^2 = .39$, $p = .008$, 95% CI [.05, .34], a non-significant main effect of cue type, $F_{(1,15)} = 2.14$, $\eta_p^2 = .13$, $p = .164$, 95% CI [.00, .06], and a non-significant interaction, $F_{(1,15)} = 1.58$, $\eta_p^2 = .10$, $p = .228$, 95% CI [NA, .40].

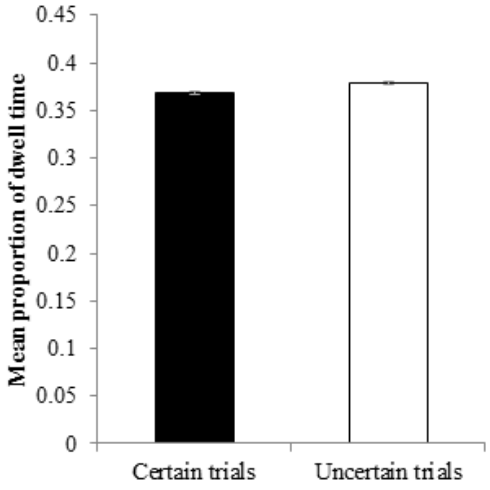


Figure 2.18a *Mean proportion of dwell time for certain and uncertain trials collapsed across trial blocks*

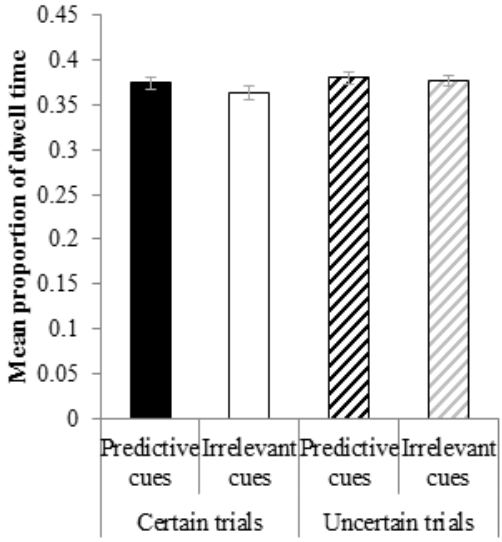


Figure 2.18b *Mean proportion of dwell time directed towards predictive cues and irrelevant cues on certain and uncertain conditions collapsed across trial blocks*

Figures 2.19a and 2.19b show the proportion of dwell time directed towards predictive and irrelevant cues over training in the certain and uncertain conditions. A three-way repeated measures ANOVA of the mean proportion of dwell time with the factors of cue type (predictive vs. irrelevant) and trial block

(1-16) and trial type (certain vs uncertain) revealed a significant main effect of trial type, $F_{(1,31)} = 7.21$, $\eta_p^2 = .19$, $p = .012$, 95% CI [.01, .40], and trial block, $F_{(5.59,173.35)} = 4.62$, $\eta_p^2 = .13$, $p < .001$, 95% CI [.03, .20], but no main effect of cue type, $F_{(1,31)} = .36$, $\eta_p^2 = .01$, $p = .550$, 95% CI [NA, .16], and a trend-level interaction between trial type and trial block, $F_{(8.2,254.21)} = 1.93$, $\eta_p^2 = .06$, $p = .055$, 95% CI [NA, .13]. The remaining interactions were non-significant, largest, $F_{(7.25,224.76)} = 1.39$, $\eta_p^2 = .04$, $p = .206$, 95% CI [NA, .07].

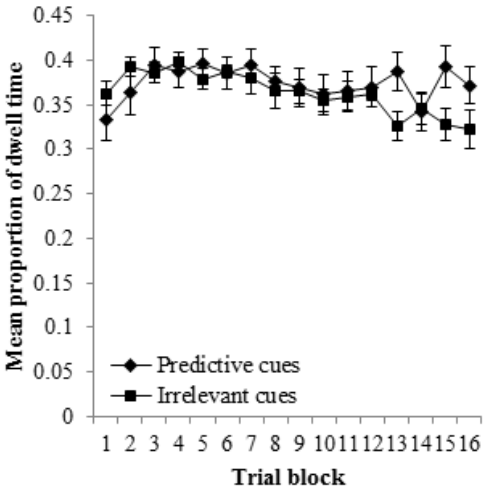


Figure 2.19a *Mean proportion of dwell time directed towards predictive cues and irrelevant cues on certain trials across trial blocks*

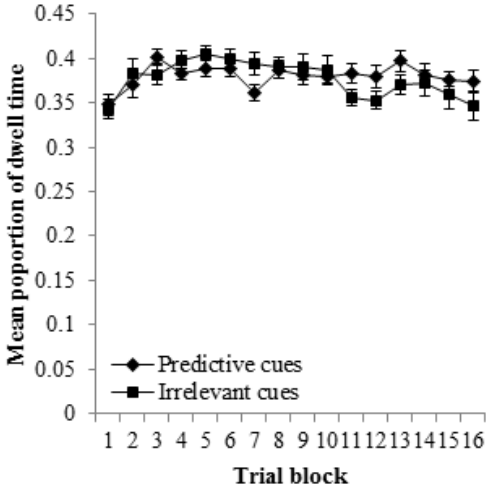


Figure 2.19b *Mean proportion of dwell time directed towards predictive cues and irrelevant cues on uncertain trials across trial blocks*

2.3.3 **Discussion**

Experiment 3 was able to replicate the finding reported by Beesley et al. (2015) that more attention was directed towards uncertain trials compared with certain trials. However, there was no difference in the amount of attention

directed towards predictive and irrelevant cues in both certain or uncertain conditions.

Accuracy steadily increased across trial blocks whilst RT decreased. However, it is noteworthy that the accuracy level on trial block 16 was lower in Experiment 3 compared to Experiment 1. This was most likely caused by the inclusion of the uncertain trials which made the task more difficult. Participants could have also generalised from uncertain trials to certain trials, even though the different colour of the certain and uncertain trial types was intended to reduce this. The level of accuracy achieved in the uncertain condition throughout training was only slightly above chance level. Nevertheless, it should be acknowledged that accuracy levels could only reach 75% for optimal performance. Also, if some participants used a probability matching strategy where they responded O1 for 75% of trials and O2 for 25% of trials which would have further reduced their accuracy.

The results showed that uncertain trials attracted a greater proportion of dwell time compared to certain trials. The notion that uncertain cues attracted increased attention has been found in animal experiments using associability (e.g. Haselgrove, Esber, Pearce & Jones, 2010) and orienting response (e.g. Pearce, Kaye & Hall, 1982; Swan & Pearce, 1988). However, this concept has been more elusive when using human participants (Hogarth et al., 2008). The Pearce-Hall (1980) model explains preferential associability of cues that predict an uncertain outcome by directing more attention towards cues that are associated with the largest prediction error. This finding can also be explained by the Esber-Haselgrove (2011) model which predicts preferential attention towards uncertain cues over certain cues. They do this by suggesting that uncertain cues

enter into two associations, one with, say O1, the other with O2, whilst certain cues only enter into one association. It is the absolute associative strength that determines the amount of attention that is attracted. Consequently, this theory predicts that attention will be more attracted to the uncertain cues than the certain cues. Finally, the Le Pelley (2004) predicts that the Pearce-Hall mechanism will be dominant over the Mackintosh mechanism if two cues have equal relative predictiveness, but a different absolute predictiveness. The current finding cannot be explained by the model of associative learning proposed by Mackintosh (1975) which predicts that attention will increase towards the cue that is the best predictor of reinforcement available on a trial. Therefore, the Mackintosh model would have predicted increased attention towards the certain trials.

However, unlike Beesley et al. (2015) and Experiment 2, at a within-trial-level no difference was found between the proportion of dwell time that was directed towards predictive and irrelevant cues. This result can be accommodated by the Pearce-Hall (1980) model because the predictiveness or irrelevance of compound cues was matched on each trial, and therefore their error terms were equal. On the other hand, we may have failed to obtain an attentional bias because participants generalised between certain and uncertain conditions. Or because they didn't receive enough training for these overt attentional biases to emerge, as demonstrated in Experiment 1.

2.4 General discussion

The experiments within Chapter 2 served as exploratory and replication investigations into the effect of relative predictiveness and uncertainty on overt visual attention in human participants. Experiment 1 examined whether various measures of eye gaze recorded during a learned predictiveness task (compounds of cues were paired with one of two outcomes, within each compound one stimulus was established as a reliable predictor of the trial outcome, whilst the other cue was undiagnostic) to determine whether they revealed a comparable effect of cue predictiveness. The findings revealed that dwell time, proportion of dwell time, fixation count, proportion of fixation count were highly correlated with each other suggesting that they all measure overt selective attention. However, latency to first fixation and fixation omission were not correlated with these other measures suggesting that, using our paradigm at least, they were a poorer measure of attention. This finding is important because previous research into the learned predictiveness effect have focused largely on the amount of dwell time and the proportion of dwell time directed towards predictive and irrelevant cues as a measure of overt attention (see: Hogarth et al. 2008; Hogarth et al., 2009; Le Pelley et al., 2011; Le Pelley et al. 2013; Mitchell et al., 2012; Wills, Lavric, Croft & Hodgson, 2007). Other measures of eye gaze have not been researched to the same extent and no research has been conducted to determine whether they are comparable measures of learned variations in overt attention.

Experiment 1 and parts of Experiments 2 and 3 examined the impact of predictive validity on overt attention during a learned predictiveness task and revealed that participants directed more overt attention towards predictive cues

compared to irrelevant cues. This finding provides support for the model of associative learning proposed by Mackintosh (1975) which claims that more attention will be directed towards cues that are the best predictors of an outcome. It also falls in line with previous research using human participants which has revealed that cues which have previously been established as good predictors of an outcome are learned about faster compared with cues that have previously been established as poor predictors (e.g. Bonardi et al., 2005; Beesley et al., 2015; Haselgrove et al., 2016; Hoffman & Rehder, 2010; Le Pelley, Beesley, & Griffiths, 2011; Le Pelley & McLaren, 2003; Le Pelley, Mitchell, & Johnson, 2013; Mitchell, Griffiths, Seetoo, & Lovibond, 2012; Rehder & Hoffman, 2005a; 2005b).

However, Experiments 2 and 3 also provided some evidence for the Pearce-Hall (1980) model which argues that more attention will be directed towards cues whose relationship with the outcome is uncertain. Using a similar methodology to that used by Hogarth et al. (2008), Experiment 2 found that at a within-trial-level more attention was directed towards predictive cues compared to irrelevant cues, but that this effect was particularly pronounced when the trial outcome was uncertain (on BX trials). In addition, overall, Experiment 3 found that uncertain trials attracted a larger proportion of dwell time compared to certain trials where the outcome could always be accurately predicted.

Experiment 1 also addressed two theoretically motivated questions. The first question was whether acquisition of the task and the acquisition of selective attention proceed at the same rate or whether one preceded the other. It was found that both measures (task learning and acquisition of selective attention) increased over training, however, the acquisition of the task proceeded at a faster

rate. This is an interesting finding because it implies that the transfer of information from the learning mechanism to the attentional mechanism is not perfect. The purpose of this lag in attention might be to keep learning conservative, to prevent the attribution high levels of salience to a cue for which only limited information has been acquired. If attention exceeded associative strength (e.g. the output from the learning system is amplified before feeding into attention) it would become abnormally sensitive to spurious correlations.

The second question was whether variations in eye gaze towards predictive and irrelevant stimuli were more immediately influenced by prediction error or predictive-success. By comparing gaze distribution and accuracy we found that participants were more likely to direct their selective attention towards the predictive cue if the previous trial with this cue compound was correct. If the previous trial was incorrect, there was little evidence for variations in attention. This provides support for the model of associative learning proposed by Mackintosh (1975) which predicts that associability will increase towards the best available predictor of reinforcement. It does not lend support for the Pearce-Hall (1980) model which predicts that a cue's associability will increase if it is uncertainly paired with an outcome.

Taken together, the findings of Experiments 1, 2 and 3 suggest that at a within-trial-level selective attention during a learned predictiveness task functions according to the model proposed by Mackintosh (1975); however, at a between-trial-level it functions according to the principles put forward in the Pearce-Hall (1980) model. Chapter 2 demonstrates that neither the Mackintosh (1975) model nor Pearce-Hall (1980) model alone can predict attentional allocation under conditions of certainty and uncertainty. However, Le Pelley

(2004) proposed a hybrid model that reconciles both the Mackintosh mechanism and Pearce-Hall mechanism by claiming that there are two different types of attention (exploitative & explorative) which combine to determine a cue's overall salience. This model explains the learned predictiveness effect on certain trials by suggesting that α (attentional associability) will increase towards predictive cues because they are a better predictor of the outcome compared with irrelevant cues. On the other hand, σ (salience associability) will be low because the outcome is fully expected as the cue is a good predictor of the outcome. Therefore, on uncertain trials σ is higher because the outcome is unpredictable.

Another model that is able to explain the overall findings from Experiments 1, 2 and 3 was proposed by Esber and Haselgrove (2011) which argues that a cue's attention is a function of the sum of its associative strengths with all outcomes. This model promotes enhanced attention towards predictive cues over irrelevant cues because it uses a summed error term which ensures that the predictive cues have higher associate strength than the irrelevant cues. However, it also accounts for the superiority of uncertain trials by arguing that they enter into more than one association (e.g. cue → O1 & cue → O2). As the sums of the associative strengths will be greater for a cue that is paired with an uncertain outcome than a cue paired consistently with the same outcome this theory predicts that attention will be more attracted to the uncertain than the certain cues.

2.5 Conclusion

Experiments 1, 2 and 3 found support for both the Mackintosh (1975) and Pearce-Hall (1980) models of associative learning. This suggests that in order to explain attentional allocation at a within-trial-level and between-trial-level, the model needs to be able to accommodate the superiority of attention towards predictive cues compared to irrelevant cues, and uncertain trials over certain trials. Models with the greatest explanatory power were proposed by Le Pelley (2004) and Esber-Haselgrove (2011).

Chapter 3:

Attention and associability

Prior to eye-tracking becoming more widely available as a measure of overt visual attention, the associability of a stimulus was used as an indirect measure because it is assumed that the speed at which a stimulus is learned about reflects, to some degree, the amount of attention it attracts (e.g. Le Pelley & McLaren, 2003; Mackintosh & Little, 1969; Pearce, Kaye & Hall, 1982; Swan & Pearce, 1988). This is demonstrated in the IDS/EDS task where subjects are initially trained on a discrimination with compounds composed of two stimuli drawn from two dimensions. One dimension is established as predictive for solving the discrimination (e.g. colour) whilst the other dimension is irrelevant (e.g. orientation). In Stage 2, subjects are presented with stimulus compounds constructed from novel stimuli drawn from the same two dimensions employed in Stage 1. In the IDS group, the same dimension that was predictive in Stage 1 (e.g. colour) is also predictive for solving the discrimination in Stage 2. However, for the EDS group, the contingency is reversed so that the dimension that was irrelevant for solving the discrimination in Stage 1 (e.g. orientation) is now predictive in Stage 2. It has been reliably found that subjects in the IDS group solve the discrimination in Stage 2 faster than the EDS group (see: Eimas, 1966; George & Pearce, 1999; Mackintosh & Little, 1969; Oswald et al., 2001; Roberts, Robbins & Everitt, 1988; Shepp & Eimas, 1964; Shepp & Schrier, 1969). An explanation as suggested by Mackintosh (1974) claims that the predictive dimension in Stage 1 acquires higher attention and therefore more easily enters into association with the outcome during Stage 2 of an IDS since the predictive dimension remains predictive – thus facilitating the discrimination. The opposite is true in an EDS because the predictive dimension in Stage 1 becomes irrelevant in Stage 2, consequently attention will be attracted

to the dimension that is irrelevant to the solution of the discrimination in Stage 2. Although this analysis of the IDS/EDS effect is popular (Mackintosh & Little, 1969; Shepp & Eimas, 1964; Shepp & Schrier, 1969), to date, eye gaze during an IDS/EDS task has not been analysed to determine whether the effect actually results from a shift in overt attention from Stage 1 into Stage 2.

With the advancement of eye-tracking technology it has also become possible to measure associability and overt attention in the same experiment. A paper by Beesley et al. (2015), described previously, used a learned predictiveness design to explore the properties of eye gaze towards cues that were imperfect predictors of reinforcement. In their second experiment, during Stage 1 in the uncertain condition, cues A and B were paired with O1 or O2, respectively, on 67% of the trials. On the remaining trials, the alternative outcome was presented. Then, in Stage 2, the predictive contingencies between A and B and novel outcomes (O3 and O4) was established as 100%. The results indicated that the attentional bias in the uncertain condition did *not* transfer like it did between Stage 1 and 2 in the certain condition, where the predictive contingencies were always 100%.

Table 3.2 *Experimental design for Experiment 2 in Beesley, Nguyen, Pearson & Le Pelley (2015)*

	Stage 1			**Stage 2**		
	Compound	***P(O1)***	***P(O2)***	***Compound***	***P(O3)***	***P(O4)***
Certain Condition	**AW**	**1**	**0**	**AW**	**1**	**0**
	AX	**1**	**0**	**BX**	**0**	**1**
	BW	**0**	**1**	**CY**	**1**	**0**
	BX	**0**	**1**	**DZ**	**0**	**1**
Uncertain Condition	**AW**	**.67**	**.33**	**AW**	**1**	**0**
	AX	**.67**	**.33**	**BX**	**0**	**1**
	BW	**.33**	**.67**	**CY**	**1**	**0**
	BX	**.33**	**.67**	**DZ**	**0**	**1**

This led Beesley et al. (2015) to suggest that the Pearce-Hall (1980) mechanism, which predicts greater attention towards uncertain cues, cannot sustain an attentional bias across a context shift (task type). On the other hand, the Mackintosh (1975) mechanism which grants preferential attention towards predictive cues is able to sustain this bias into novel contexts. However, a possible flaw with Beesley et al.'s experimental design is that the predictive contingencies for the certain condition were 100% in Stage 1 and 100% in Stage 2, but the predictive contingencies for the uncertain condition were 67% in Stage 1 and 100% in Stage 2 – consequently it wasn't just the context (Stage 1 – Stage 2) that was changed. Therefore, the goal of the experiments in the current chapter were to employ two methods of detecting learned variations in associability and dwell time. One method kept the outcome the same but changed the stimuli between training and test (the IDS-EDS procedure), and the second method kept the stimuli the same but changed the outcomes (a learned predicitveness procedure).

3.1 Experiment 4

The aim of Experiment 4 was to quantify, using eye-tracking methodology, the amount of overt visual attention directed towards predictive and irrelevant cues during a modified IDS/EDS task in which the same outcomes were predicted by different compound cues which contained elements that were more or less relevant as predictors of the outcome in Stage 1 and 2. The task was modified so that the two dimensions did not occupy the same space as the eye-tracker would not be able to differentiate between which dimension participants were attending to. This was achieved by creating an artificial IDS/EDS design in which different coloured cues were established as predictive and irrelevant dimensions.

3.1.1 **Method**

3.1.1.1 ***Participants***

Forty-nine undergraduate or postgraduate students from The University of Nottingham participated in return for a payment of £3. The sample consisted of 31 females (Mean ± SD: 22.13 ± 2.73). Exclusion criteria included not having normal or corrected-to-normal vision or visual disturbances triggered by flashing lights.

3.1.1.2 ***Apparatus and Stimuli***

Experiment 4 was designed and run using Experiment Builder. A SR Research Eyelink II eye-tracker sampled participant's right eye at a rate of 1000

Hz. Thresholds used to define fixations and saccades were: .15° displacement, 30°/s velocity and 8,000°/s2 acceleration. Participants viewed stimuli binocularly from a distance of 58.5 cm and their head movements were minimised with a chin rest. A professional series p227f ViewSonic CRT monitor (48 × 48 cm) was used to display stimuli and screen resolution was set to 1026 × 768. A high (3000 Hz) and a low (300 Hz) pitched tone served as trial outcomes, which were presented for 596 and 264 ms respectively. Outcomes were heard via a TEAC PowerHA 200 stereo speaker system and participants made their response using key number 1 (high pitched) or number 2 (low pitched) buttons on a keyboard.

A fixation cross was presented in the centre of the screen for 1000 ms at the start of each trial. Stimuli consisted of eight geometric patterns, each comprising equal numbers of black or red, and white triangles (see Figure 3.1). Stimuli that served as predictive cues (A, B, C & D) were counterbalanced with stimuli that served as irrelevant cues (W, X, Y & Z), as well as colour (black or red) (see Table 3.1 and Appendix 4 for full counterbalancing). Stimuli had an area of 11 cm^2, so regions of interest were set to this size, and subtended a visual angle of 11.25°[2]. The centre of each pattern was separated by 4 cm to the centre of the screen with a grey background (see Figure 3.2).

Table 3.1 *Experimental design for Experiment 4*

	Stage 1		Stage 2	
	Compound	*Outcome*	*Compound*	*Outcome*
IDS	AX	1	CV	1
	AY	1	CW	1
	BX	2	DV	2
	BY	2	DW	2
EDS	AX	1	CV	1
	AY	1	CW	1
	BX	2	DV	2
	BY	2	DW	2

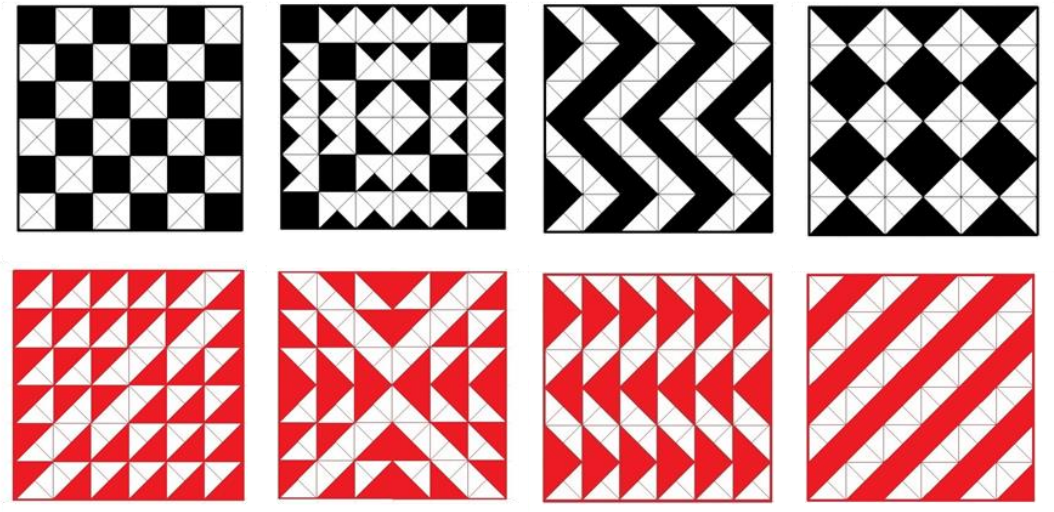


Figure 3.1 *Experimental stimuli for Experiment 4*

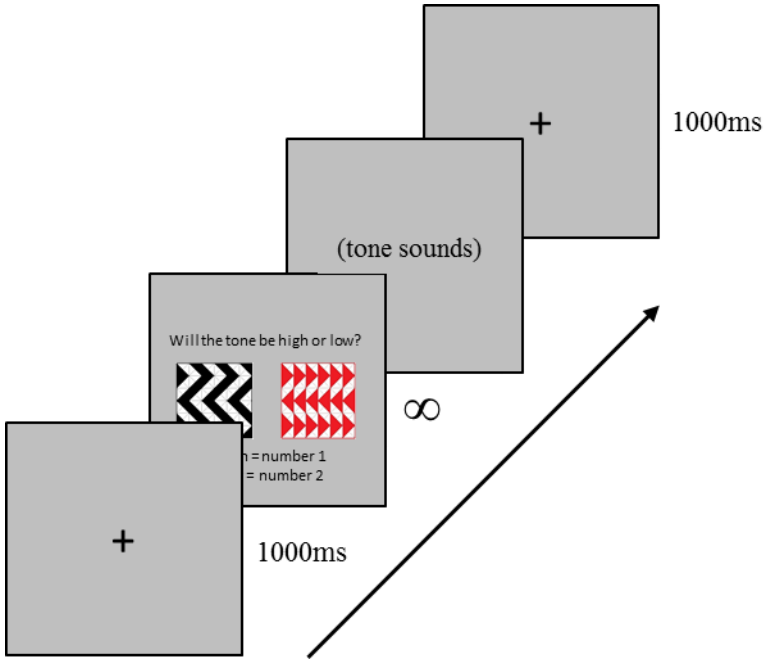


Figure 3.2 *Temporal layout of a trial during Experiment 4*

3.1.1.3 ***Procedure***

A brief health questionnaire was administered to screen participants for exclusion criteria, written and verbal instructions were given and informed consent was gained. At the start of each experimental session the experimenter checked that both pupil and corneal reflections were present (pupil only tracking was used for four participants), whilst participants read on-screen instructions before performing a calibration. The following on-screen instructions were presented: "*Thank you for participating in this study. Your first task is to focus on the dot and follow it with your eyes. Press any key on the keyboard to begin the experiment".* The eye-tracker was then calibrated for each participant using a nine-point calibration, except for four participants who could only be calibrated using a five-point procedure. Further instructions read: "*In the next phase of the experiment two patterns will be presented on the screen. Your task is to decide whether the tone which*

follows will be high or low in pitch. High pitched = key number 1. Low pitched = key number 2. (Press any key to start the experiment)". Between Stage 1 and 2 the following instructions were displayed: *"In the second phase you will see some different patterns. Your task is to decide whether the tone that follows will be high or low in pitch. High pitched = key number 1. Low pitched = key number 2. (Press any key to start the experiment)".* At the end of the experiment a grey screen with the words: "*End of experiment. Thank you for taking part.*" appeared on the screen for 5000 ms.

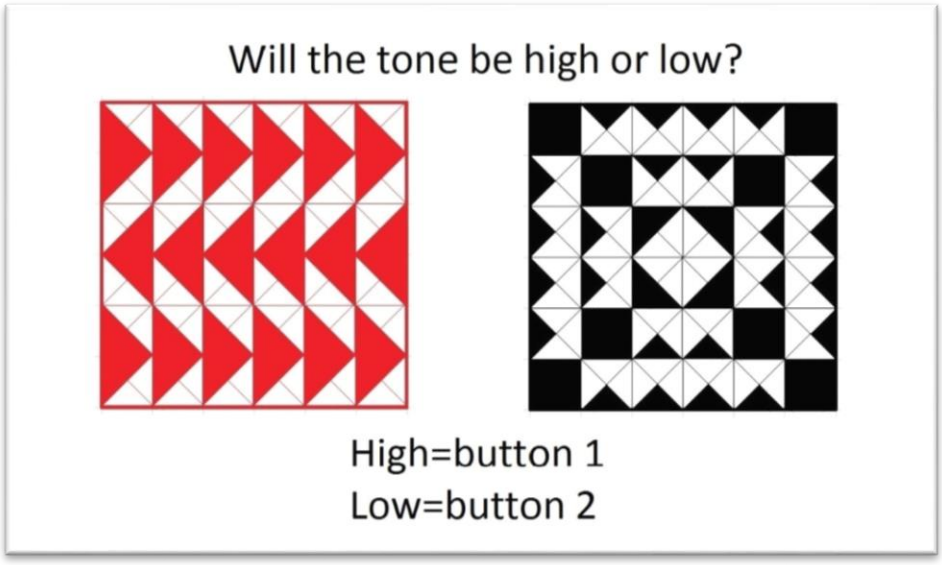


Figure 3.3 *Spatial layout of a trial during Experiment 4*

The experiment was self-paced with stimuli terminating upon response. Trial order was randomised within stage and each compound was presented 16 times per block, an equal number of times on the left and the right-hand side of the screen; consequently, the entire experiment consisted of 256 trials. After participants had responded using key number 1 or 2, the screen went blank whilst they received audio feedback (high or low pitched tone) as to whether

they were correct or incorrect. Upon completion participants were thanked for their time and debriefed.

3.1.2 **Results**

In order to demonstrate the IDS/EDS effect it is important that participants learned the contingencies in Stage 1; therefore, participants that failed to reach 60% accuracy were removed from further analysis (eleven participants were excluded on this basis). Four additional participants were removed on the basis of poor eye-tracking (>20% missing data), and finally two participants were removed due to a coding error. All participants were replaced with additional participants to complete counterbalancing. Based on the findings of Chapter 2, the analysis in Chapter 3 was constrained to the mean proportion of dwell time. For subsequent analysis Greenhouse-Geisser corrections were applied where sphericity was violated.

3.1.2.1 ***Behavioural data***

Figure 3.4a reveals that the mean proportion of correct trials increased across Stage 1 and 2 in both the IDS and EDS conditions. Consistent with previous demonstrations of the IDS/EDS effect, performance was superior in the IDS group relative to the EDS group in Stage 2. However, to our surprise, there was also an indication of a difference between groups in Stage 1, but this difference was not present by the end of Stage 1.

A two-way mixed measures ANOVA of accuracy in Stage 1 with the within-factor of trial block (1-8) and between-factor of shift (IDS vs. EDS) revealed a significant main effect of trial block, $F_{(3.27,45.81)} = 10.26$, $\eta_p^2 = .42$, $p < .001$, 95% CI [.17, .55], a non-significant main effect of shift, $F_{(1,14)} = 1.70$, $\eta_p^2 = .11$, $p = .213$, 95% CI [NA, .40], and a significant interaction, $F_{(3.27,45.81)} = 20.55$, $\eta_p^2 = .60$, $p < .001$, 95% CI [.37, .69]. Simple main effects analysis of the interaction revealed a significant difference between IDS and EDS conditions on blocks 4, 5, 6 and 7, smallest, $F_{(1,14)} = 5.09$, $\eta_p^2 = .27$, $p = .041$, 95% CI [NA, .52], with higher accuracy in the IDS condition. A two-way mixed measures ANOVA of accuracy in Stage 2 with the within-factor of trial block (1-8) and between-factor of shift (IDS vs. EDS) revealed a trend-level main effect of trial block, $F_{(4.48,62.77)} = 2.26$, $\eta_p^2 = .14$, $p = .066$, 95% CI [NA, .25], a non-significant main effect of shift, $F_{(1,14)} = .004$, $\eta_p^2 = .000$, $p = .950$, 95% CI [NA, .08], and a significant interaction, $F_{(4.48,62.77)} = 4.07$, $\eta_p^2 = .23$, $p = .004$, 95% CI [.03, .35]. Simple main effects analysis of the interaction revealed a significant difference between IDS and EDS conditions on blocks 2 and 5, smallest, $F_{(1,14)} = 5.09$, $\eta_p^2 = .27$, $p = .041$, 95% CI [NA, .53], with higher accuracy in the IDS condition.

Figure 3.4b shows that the mean RT decreased in both the IDS and EDS conditions across Stage 1 and 2. A two-way mixed measures ANOVA of RT in Stage 1 with the within-factor of trial block (1-8) and between-factor of shift (IDS vs. EDS) revealed a significant main effect of trial block, $F_{(3.35,46.94)} = 9.43$, $\eta_p^2 = .40$, $p < .001$, 95% CI [.15, .54], a non-significant main effect of shift, $F_{(1,14)} = 1.57$, $\eta_p^2 = .10$, $p = .231$, 95% CI [NA, .40], and a significant interaction, $F_{(3.08,184.50)} = 15.70$, $\eta_p^2 = .53$, $p < .001$, 95% CI [.10, .20]. Simple main effects

analysis of the interaction revealed a significant difference between IDS and EDS conditions on blocks 4, 5, 6 and 8, smallest, $F_{(1,14)} = 6.01$, $\eta_p^2 = .30$, $p = .028$, 95% CI [.04, .41] with faster RT in the IDS condition. A two-way mixed ANOVA of RT in Stage 2 with the within-factor of trial block (1-8) and between-factor of shift (IDS vs. EDS) revealed a significant main effect of trial block, $F_{(3.10,43.41)} = 5.88$, $\eta_p^2 = .30$, $p < .001$, 95% CI [.06, .45], a non-significant main effect of shift, $F_{(1,14)} = .08$, $\eta_p^2 = .005$, $p = .788$, 95% CI [NA, .22], and a significant interaction, $F_{(3.10,43.41)} = 12.03$, $\eta_p^2 = .46$, $p < .001$, 95% CI [.20, .59]. Simple main effects analysis of the interaction revealed a significant difference between IDS and EDS conditions on blocks 1, 4, 5, 6 and 7, smallest, $F_{(1,14)} = 6.43$, $\eta_p^2 = .32$, $p = .024$, 95% CI [.08, .43], with faster RT in the IDS condition.

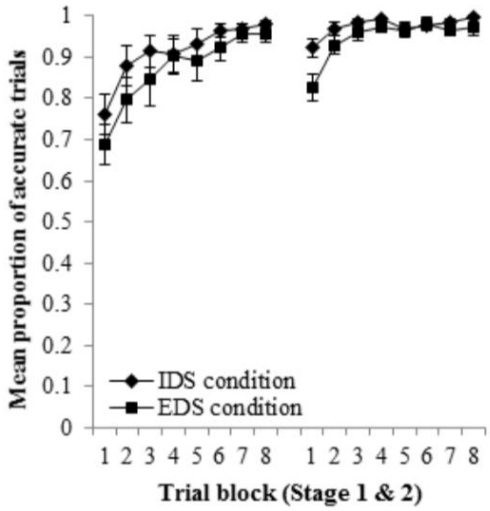


Figure 3.4a *Mean proportion of accuracy across trial blocks in Stage 1 and Stage 2*

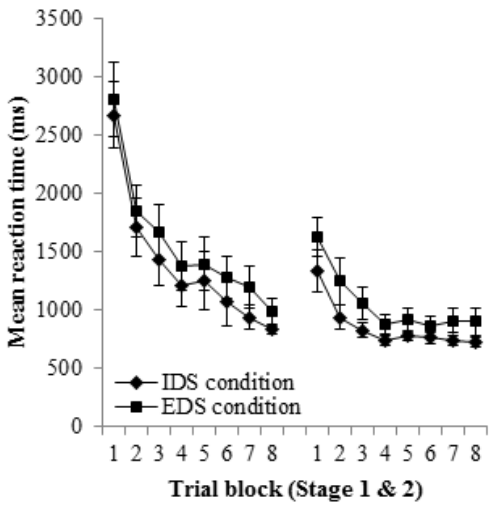


Figure 3.4b *Mean reaction time across trial blocks in Stage 1 and Stage 2*

3.1.2.2 ***Eye gaze analysis***

As RT was longer in the EDS condition the mean proportion of dwell time was calculated as a percentage of the RT for each trial. Figure 3.5 demonstrates that the mean proportion of dwell time directed towards predictive cues in both the IDS and EDS conditions increased at the expense of irrelevant cues. There was a slight reduction in the proportion of dwell time directed towards the predictive cues and increase in the proportion of dwell time directed towards irrelevant cues at the outset of Stage 2.

A three-way mixed ANOVA of dwell time in Stage 1 with the within factors of cue type (predictive vs. irrelevant) and trial block (1-8), and between-factor of shift (IDS vs. EDS) revealed a significant main effect of cue type, $F_{(1,14)} = 37.65$, $\eta_p^2 = .73$, $p < .001$, 95% CI [.35, .84], a non-significant main effect of trial block, $F_{(3.44,48.09)} = .27$, $\eta_p^2 = .02$, $p = .874$, 95% CI [NA, .07], and shift, $F_{(1,14)} = .18$, $\eta_p^2 = .01$, $p = .682$, 95% CI [NA, .25]. The main effect of cue type interacted with trial block, $F_{(2.57,35.92)} = 8.14$, $\eta_p^2 = .37$, $p = .001$, 95% CI [.10, .53], but no other interactions were significant, Fs ≤ 1.92, Ps $\geq .187$. Simple main effects analysis of the interaction between cue type and trial block revealed a significant difference between predictive and irrelevant cues from trial block 1 onwards, smallest, $F_{(1,14)} = 4.87$, $\eta_p^2 = .26$, $p = .045$, 95% CI [NA, .54], with predictive cues always attracting a higher proportion of dwell time.

A three-way mixed measures ANOVA of proportion of dwell time in Stage 2 with the within factors of cue type (predictive in Stage 2 vs. irrelevant in Stage 2) and trial block (1-8), and between-factor of shift (IDS vs. EDS) revealed a significant main effect of cue type, $F_{(1,14)} = 61.86$, $\eta_p^2 = .82$, $p < .001$, 95% CI

[.54, .89], trial block, $F_{(3.15,44.04)} = 4.51$, $\eta_p^2 = .24$, $p = .007$, 95% CI [.02, .40], and a non-significant main effect of shift, $F_{(1,14)} = .1.77$, $\eta_p^2 = .11$, $p = .205$, 95% CI [NA, .41]. No interactions were significant, Fs ≤ 61.86, Ps ≥ .241.

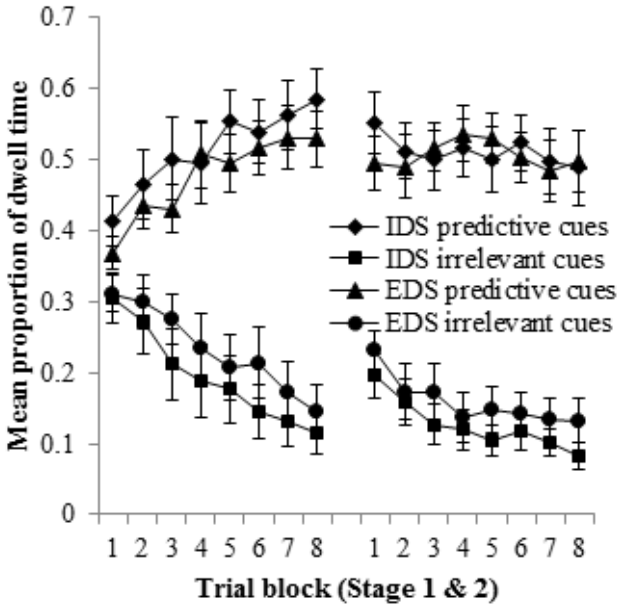


Figure 3.5 *Mean proportion of dwell time across trial blocks in Stage 1 and Stage 2*

3.1.2.3 *First nine trials after the shift*

It was anticipated that any bias in attention towards predictive and irrelevant cues during IDS and EDS conditions would be most apparent at the onset of Stage 2. Figure 3.6a demonstrates that the mean proportion of dwell time directed towards predictive cues in the first nine trials in Stage 2 during the IDS condition increased at the expense of irrelevant cues. Figure 3.6b shows the same pattern during the EDS condition, except this effect was smaller in the first six trials. Furthermore, in the EDS condition a larger proportion of dwell time

was directed towards irrelevant cues than predictive cues for the first two trials in Stage 2.

A three-way mixed ANOVA of mean proportion of dwell time with the within-factors of trial block (1-3) and cue type (predictive vs. irrelevant), and the between factor of shift (IDS vs. EDS) revealed a significant main effect of cue type, $F_{(1,30)} = 34.59$, $\eta_p^2 = .54$, $p < .001$, 95% CI [.26, .68], a non-significant main effect of trial block, $F_{(2,60)} = 1.39$, $\eta_p^2 = .04$, $p = .257$, 95% CI [NA, .16], and shift, $F_{(1,30)} = .09$, $\eta_p^2 = .003$, $p = .771$, 95% CI [NA, .13]. The main effect cue type interacted with trial bin, $F_{(2,60)} = 9.10$, $\eta_p^2 = .23$, $p < .001$, 95% CI [.06, .38], but no other interactions were significant, Fs ≤ 1.12, Ps $\geq .332$. Simple main effects analysis of the interaction between cue type and trial bin revealed a significant difference between predictive and irrelevant cues on all three bins, smallest, $F_{(2,60)} = 4.99$, $\eta_p^2 = .14$, $p < .033$, 95% CI [.01, .29], with predictive cues always attracting a larger proportion of dwell time irrespective of shift group.

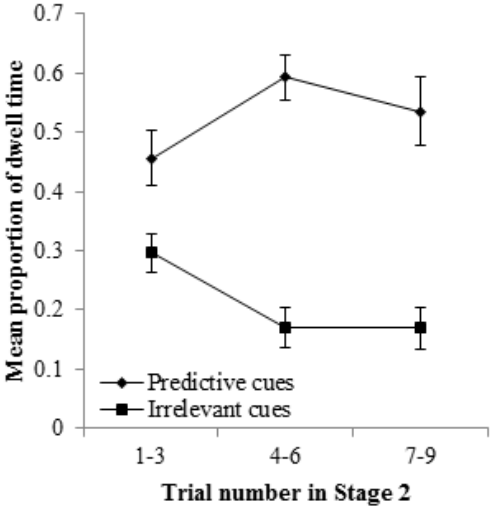


Figure 3.6a *Mean proportion of dwell time directed towards predictive and irrelevant cues across the first nine trials in Stage 2 in the IDS condition*

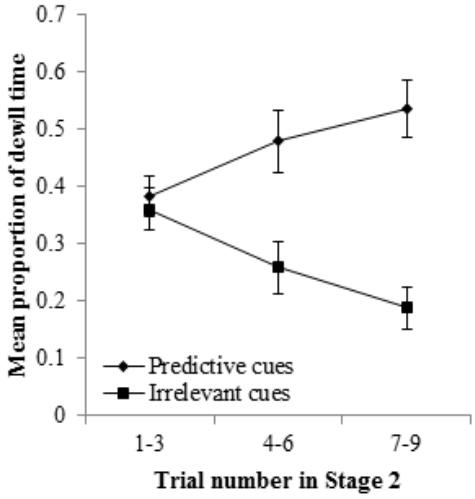


Figure 3.6b *Mean proportion of dwell time directed towards predictive and irrelevant cues across the first nine trials in Stage 2 in the EDS condition*

3.1.2.4 *Trials following a IDS or EDS shift*

Further analysis was conducted into this early difference in attentional bias between the IDS and EDS conditions by comparing trial 128, which is the last trial in Stage 1, with trial 129, which is the first trial in Stage 2. Figure 3.7a shows that the mean proportion of dwell time directed towards predictive cues was larger than the mean proportion of dwell time directed towards irrelevant cues on trial 128 in the IDS condition, and this effect was also maintained into trial 129. Figure 3.7b shows that a larger proportion of dwell time was also directed towards predictive cues compared with irrelevant cues on trial 128 in the EDS condition. However, on trial 129 this effect was reversed with (the now) irrelevant cues attracting a larger proportion of dwell time compared to predictive cues.

A three-way mixed measures ANOVA of mean proportion of dwell time with the within-factors of trial number (128 vs. 129) and cue type (predictive vs. irrelevant), and the between factor of shift (IDS vs. EDS) revealed a significant main effect of cue type, $F_{(1,30)} = 24.39$, $\eta_p^2 = .45$, $p < .001$, 95% CI [.17, .62], a trend-level main effect of trial number, $F_{(1,30)} = 3.74$, $\eta_p^2 = .11$, $p = .062$, 95% CI [NA, .32], and a non-significant main effect of shift, $F_{(1,30)} = 937.30$, $\eta_p^2 = .03$, $p = .342$, 95% CI [.94, .98]. The main effect cue type interacted with shift, $F_{(1,30)} = 4.80$, $\eta_p^2 = .14$, $p = .036$, 95% CI [.06, .32], and trial number interacted with cue type, $F_{(1,30)} = 51.33$, $\eta_p^2 = .63$, $p < .001$, 95% CI [.43, .73]. There was also a three-way interaction between trial number, shift and cue type, $F_{(1,30)} = 4.34$, $\eta_p^2 = .13$, $p = .046$, 95% CI [NA, .31]. Simple main effects analysis of the interaction between cue type and shift revealed a significant difference between predictive

and irrelevant cues in the IDS only, $F_{(1,30)} = 25.41$, $\eta_p^2 = .46$, $p < .001$, 95% CI [.22, .60], with predictive cues always attracting a larger proportion of dwell time. The interaction between cue type and trial number revealed a significant difference between predictive and irrelevant cues on trial 128 only, $F_{(1,30)} = 78.79$, $\eta_p^2 = .72$, $p < .001$, 95% CI [.56, .80], with predictive cues always attracting a larger proportion of dwell time.

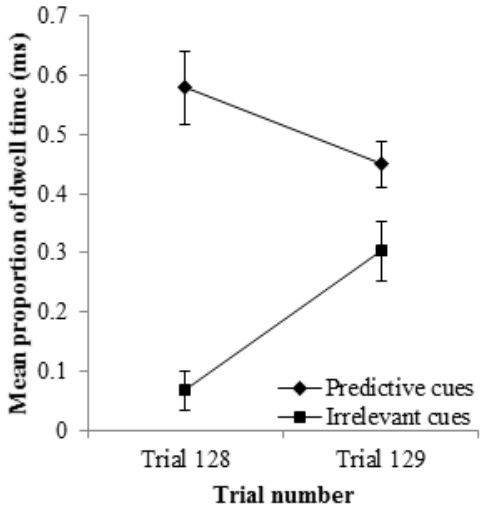


Figure 3.7a *Mean proportion of dwell time on the last trial of Stage 1 and first trial in Stage 2 in the IDS condition*

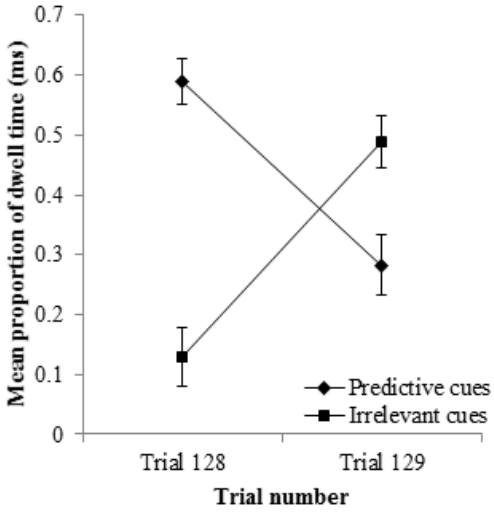


Figure 3.7b *Mean proportion of dwell time on the last trial of Stage 1 and first trial in Stage 2 in the EDS condition*

3.1.3 **Discussion**

Experiment 4 measured the proportion of dwell time directed towards predictive and irrelevant cues during a modified version of an IDS/EDS task. Analysis revealed that participants acquired an attentional bias towards predictive cues in Stage 1 which transferred into the early trials of Stage 2.

However, in the EDS condition this bias was only maintained for two trials in Stage 2.

It is clear that participants were able to solve the discrimination in both the IDS and EDS conditions because accuracy increased whilst RT decreased. Accuracy in Stage 2 was higher for the IDS condition which falls in line with previous IDS/EDS experiments which find fewer errors in the IDS condition (Eimas, 1966; George & Pearce, 1999; Mackintosh & Little, 1969; Oswald et al., 2001; Roberts, Robbins & Everitt, 1988; Shepp & Eimas, 1964; Shepp & Schrier, 1969). RT was also faster in Stage 2 of the IDS condition than in Stage 2 of the EDS condition.

Results also revealed that the attentional bias (proportion of dwell time) towards predictive cues and away from irrelevant cues, demonstrated in the learned predictiveness effect, was replicated in Stage 1 in both the IDS and EDS conditions. However, this overt attentional bias was ephemeral because when the predictive contingencies changed (Stage 2) eye gaze quickly followed suit, but learning was slower to change. This finding is curious, because Experiment 1 revealed that discrimination performance proceeded more rapidly than overt changes in attention. One notable difference between Experiment 1 and the current experiment is the presence of a switch in stimulus validity. Perhaps attentional changes can outpace learned behaviour when expectations are substantially violated, as is the case when dimensional validity is changed in the EDS condition.

In Stage 2 of the IDS condition the attentional bias established during Stage 1 transferred, however, in the EDS condition this bias was only

maintained for two trials before attention shifted towards the 'new' predictive cues that were irrelevant in Stage 1. This provides the first direct evidence that the IDS/EDS effect is associated with an attentional bias established in Stage 1 being generalised into Stage 2 at the start of both conditions. Although, the observation that this attentional bias lasts such a brief time in Stage 2 of the EDS condition suggests that participants were very sensitive to trial feedback, requiring only two error signals before shifting their attention.

During trial block 1 of Stage 2, the proportion of dwell time directed towards irrelevant cues during the IDS and EDS conditions was renewed slightly. An explanation for this could be that cues attracted more attention because they were novel, or because the transfer of attention, like associability, is not perfect across the context shift.

3.2 Experiment 5

Using a methodological design which used the same compound cues in Stage 1 and 2 but changed the outcomes they predicted, the aim of Experiment 5 was to investigate whether it was possible to obtain learned variations in attention if the predictive contingencies were lower than 100%. As described in the introduction to this chapter, Beesley et al. (2015) used a learned predictiveness design to explore the properties of eye gaze towards cues that were imperfect predictors of reinforcement. The results indicated that the attentional bias in the uncertain condition did *not* transfer like it did between Stage 1 and 2 in the certain condition, where the predictive contingencies were always 100%. However, during the test phase, the predictive contingencies were always 100% and this might have impacted attentional transference towards cues that were previously less than 100% predictive of the outcome.

Experiment 5 aimed to reduce the number of changes between Stage 1 training and Stage 2 training so that more concrete conclusions between cause and effect can be drawn. To do this, a variation of the learned predictiveness task was employed where instead of all compounds being equally predictive of the outcomes (O3/O4) in Stage 2, the predictive contingencies established in Stage 1 persist into Stage 2 to see whether the attentional bias was able to transfer from Stage 1 into Stage 2 (see Table 3.3). For example, in the congruent conditions, the same cues (A & B) predict the outcomes in Stage 1 (O1 & O2) and Stage 2 (O3 & O4) with the same predictive certainty (either 75% or 100%). But in the incongruent conditions, different cues predicted the outcomes in Stage 1 (A & B)

and Stage 2 (V & W), although still with the same predictive certainty (either 75% or 100%).

Table 3.2 *Experimental design of Experiment 5*

	Stage 1			Stage 2		
	Compound	*Probability of outcome 01*	*Probability of outcome 02*	*Compound*	*Probability of outcome 03*	*Probability of outcome 04*
Congruent 100% condition	**AV**	**1**	**0**	**AV**	**1**	**0**
	AW	**1**	**0**	**AW**	**1**	**0**
	BV	**0**	**1**	**BV**	**0**	**1**
	BW	**0**	**1**	**BW**	**0**	**1**
Incongruent 100% condition	**AV**	**1**	**0**	**AV**	**1**	**0**
	AW	**1**	**0**	**AW**	**0**	**1**
	BV	**0**	**1**	**BV**	**1**	**0**
	BW	**0**	**1**	**BW**	**0**	**1**
Congruent 75% condition	**AV**	**.75**	**.25**	**AV**	**.75**	**.25**
	AW	**.75**	**.25**	**AW**	**.75**	**.25**
	BV	**.25**	**.75**	**BV**	**.25**	**.75**
	BW	**.25**	**.75**	**BW**	**.25**	**.75**
Incongruent 75% condition	**AV**	**.75**	**.25**	**AV**	**.75**	**.25**
	AW	**.75**	**.25**	**AW**	**.25**	**.75**
	BV	**.25**	**.75**	**BV**	**.75**	**.25**
	BW	**.25**	**.75**	**BW**	**.25**	**.75**

3.2.1 **Methods**

3.2.1.1 ***Participants***

Sixty-five undergraduate or postgraduate students from The University of Nottingham participated in return for a payment of £3. The sample consisted of 44 females (Mean±SD:19.70±2.08). Exclusion criteria were the same as in previous experiments.

3.2.1.2 *Apparatus and stimuli*

Experiment 5 was designed and run using Experiment Builder. A SR (Mississauga, Canada) Research Eyelink 1000 eye-tracker sampled participant's right eye at a rate of 1000 Hz. Participants viewed stimuli binocularly from a distance of 56 cm, and their head movements were minimised via a chin and forehead rest. A graphic series G90FB ViewSonic CRT monitor (44 × 44 cm) was used to display stimuli and screen resolution set to 1026 × 768. Thresholds used to define fixations and saccades were: .15° displacement, 30°/s velocity and 8,000°/s2 acceleration.

Stimuli serving as cues A, B, C, D, W, X, Y and Z consisted of eight geometric patterns; the same ones used in Experiment 1. Stimuli were 11 cm^2 and regions of interest (ROI) were set to this size. The cues for each compound were presented 4 cm apart, in the centre of the screen with a white background. Stimuli subtended a visual angle of 11.25°^{2}. Stimuli that served as predictive cues (A, B, C & D) were counterbalanced with the stimuli that served as irrelevant cues (W, X, Y & Z) (see Appendix 5 for full counterbalancing).

The experiment employed a between-measures design (see Table 3.3). In Stage 1, cues A and B were established as predictive of outcome O1 (high pitched tone, 3000 Hz, 596 ms) or O2 (low pitched tone, 300 Hz, 264 ms). For the certain condition this relationship was 100% predictive, but for the uncertain condition the relationship was reduced to 75%. In Stage 2, cues A and B were established as predictive of outcome O3 (click sound, 100 ms) or O4 (bell ring, 200 ms). For the certain condition this relationship was maintained at 100% predictive of the outcome and for the uncertain condition cues were maintained

at 75% predictive. Outcomes were heard via a TEAC PowerHA 200 stereo speaker system. Participants made predictive responses using the letter 'J' (high pitch tone), letter 'D' (low pitch tone), letter 'Y' (bell ring) or letter 'B' (click sound) on the keyboard.

3.2.1.3 ***Procedure***

The experiment was carried out using an EyeLink 1000 eye-tracker, and consequently the set up and calibration procedure was the same as Experiment 1. However, as this experiment used four audio outcomes these were played to participants before the start of the experiment so they knew which each sound was. Participants were calibrated using a nine-point procedure, except for two participants that could only be calibrated using a five-point procedure. After calibration, participants read the following written instructions: "*Thank you for participating in this study. Your first task is to focus on the dot and follow it with your eyes. Press any key on the keyboard to begin the experiment. In next phase of the experiment two patterns will be presented on the screen. Your task is to decide whether the tone which follows will be high or low. High pitched = key 'J' Low pitched = key 'D' (press any key to start the experiment).*"

The experiment was self-paced and after Stage 1 had been completed further instructions appeared which informed participants that they would now see the same patterns again but that this time they needed to predict whether they thought a bell ring or click sound would follow, and make the appropriate key response (B or Y). *"In the next phase of the experiment two different patterns will be presented on the screen. Your task is to decide whether the sound that will follow will be*

a 'bell ring' or a 'click sound'. Bell = key 'Y' Click = key 'B' (press any key to start the experiment). End of experiment. Thank you for your participation in this study."

Trial order was randomised within stages and participants were trained over 8 trial blocks in each stage, with eight compounds being presented in each trial block. Each compound was presented 16 times, an equal number of times on the left and right-hand side of the screen; consequently, the entire experiment consisted of 256 trials. After participants had responded using the keyboard the screen went blank whilst they received audio feedback (high or low-pitched tone in Stage 1 & bell ring or click sound in Stage 2) as to whether they were correct or incorrect. Upon completion participants were thanked for their time and debriefed.

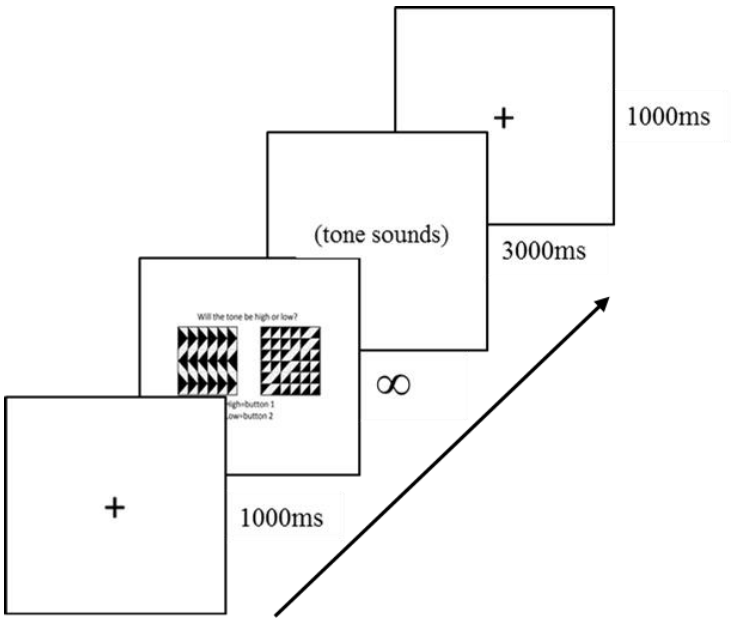


Figure 3.8 *Temporal layout of a trial during Experiment 5*

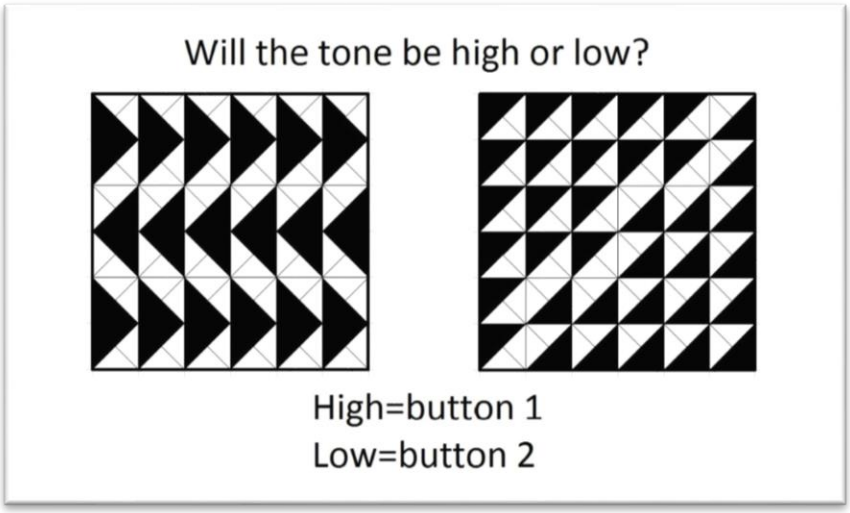


Figure 3.9 *Spatial layout of a trial during Experiment 5*

3.2.2 **Results**

Exclusion criteria were set to less than 60% correct responses across all trial blocks in Stage 1 during the 100% contingency conditions (one participant was excluded on this basis). Two additional participants were removed on the basis of poor eye-tracking (>20% missing data). All three participants were replaced with additional participants to complete counterbalancing. For subsequent analysis Greenhouse-Geisser corrections were applied where sphericity was violated.

3.2.2.1 ***Behavioural data***

Figure 3.10a shows that the mean proportion of correct trials increased across Stage 1 and 2 for all conditions: congruent100%, incongruent100%, congruent75% and incogruent75%. A three-way mixed measures ANOVA of accuracy in Stage 1 with the within-factor of trial block (1-8), and between-

factors of shift (congruent vs. incongruent) and certainty (100% vs. 75%) revealed a significant main effect of trial block, $F_{(5.66,339.79)} = 11.30$, $\eta_p^2 = .16$, $p < .001$, 95% CI [.08, .36], certainty, $F_{(1,60)} = 58.91$, $\eta_p^2 = .50$, $p < .001$, 95% CI [.33, .59], and a non-significant main effect of shift, $F_{(1,60)} = .01$, $\eta_p^2 = .00$, $p = .941$, 95% CI [NA, .05]. All interactions were non-significant, largest, $F_{(5.66,339.79)} = 1.13$, $\eta_p^2 = .02$, $p = .344$, 95% CI [NA, .03].

A three-way mixed ANOVA of accuracy in Stage 2, with the within-factor of trial block (1-8), and between-factors of shift (Congruent vs. Incongruent) and certainty (100% vs. 75%) revealed a significant main effect of trial block, $F_{(5.98, 358.76)} = 4.39$, $\eta_p^2 = .07$, $p < .001$, 95% CI [.02, .20], certainty, $F_{(1,60)} = 36.23$, $\eta_p^2 = .38$, $p < .001$, 95% CI [.22, .50], and a non-significant effect of shift, $F_{(1,60)} = .35$, $\eta_p^2 = .01$, $p = .557$, 95% CI [NA, .07]. All interactions were non-significant, largest $F_{(5.98,358.76)} = 2.04$ $\eta_p^2 = .03$, $p = .060$, 95% CI [NA, .05].

The mean RT decreased across Stage 1 and 2 for all conditions (see Figure 3.10b). A three-way mixed measures ANOVA of RT in Stage 1 with the within-factor of trial block (1-8), and between-factors of shift (congruent vs. incongruent) and certainty (100% vs. 75%) revealed a significant main effect of trial block, $F_{(3.08,184.50)} = 30.43$, $\eta_p^2 = .34$, $p < .001$, 95% CI [.24, .49], certainty, $F_{(1,60)} = 13.57$, $\eta_p^2 = .184$, $p < .001$, 95% CI [.06, .32], and a non-significant main effect of shift, $F_{(1,60)} = 1.60$, $\eta_p^2 = .03$, $p = .211$, 95% CI [NA, .12]. All interactions were non-significant, largest, $F_{(3.08,184.50)} = 1.23$, $\eta_p^2 = .02$, $p = .301$, 95% CI [NA, .05].

A three-way mixed measures ANOVA of RT in Stage 2, with the within-factor of trial block (1-8), and between-factors of shift (congruent vs.

incongruent) and certainty (100% vs. 75%) revealed a significant main effect of trial block, $F_{(4,239.98)} = 15.18$, $\eta_p^2 = .202$, $p < .001$, 95% CI [.12, .26], certainty, $F_{(1,60)} = 17.01$, $\eta_p^2 = .22$, $p < .001$, 95% CI [.08, .36], and a non-significant main effect of shift, $F_{(1,60)} = .09$, $\eta_p^2 = .001$, $p = .767$, 95% CI [NA, .05]. All interactions were non-significant, largest, $F_{(4,239.98)} = .84$, $\eta_p^2 = .01$, $p = .501$, 95% CI [NA, .03].

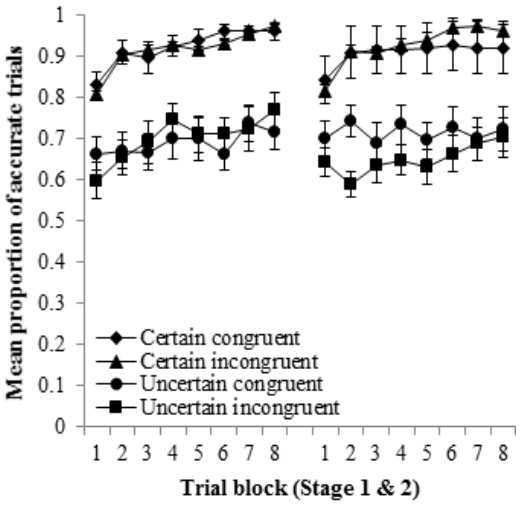


Figure 3.10a *Mean proportion of accurate trials across trial blocks during Stage 1 and Stage 2 in all conditions*

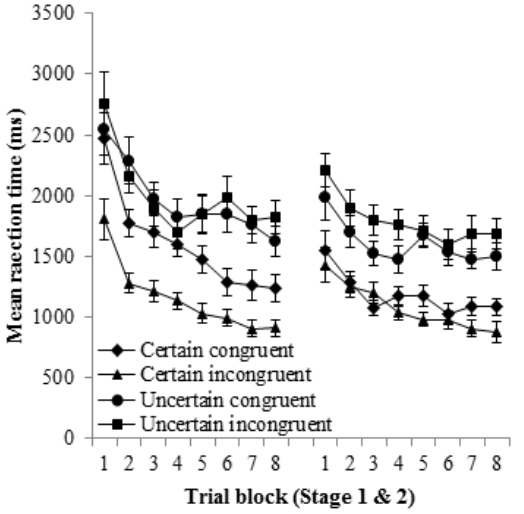


Figure 3.10b *Mean reaction time (ms) across trial blocks during Stage 1 and Stage 2 in all conditions*

3.2.2.2 *Eye gaze analysis*

Figures 3.11a and 3.11b demonstrate that the mean proportion of dwell time directed towards predictive cues in the congruent100% and incongruent100% conditions increased relative to the irrelevant cues. Figures 3.11c and 3.11d show that there was no clear difference in the proportion of dwell time directed towards predictive and irrelevant cues in the congruent75% and incongruent75% conditions.

A four-way mixed measures ANOVA of dwell time in Stage 1 with the within factors of cue type (predictive vs. irrelevant) and trial block (1-8), and between-factors of shift (congruent vs. incongruent) and certainty (100% vs. 75%) revealed a significant main effect of cue type, $F_{(1,60)} = 33.31$, $\eta_p^2 = .36$, $p < .001$, 95% CI [.00, .18], trial block, $F_{(4.84,290.50)} = 5.02$, $\eta_p^2 = .08$, $p < .001$, 95% CI [NA, .49], certainty, $F_{(1,60)} = 8.89$, $\eta_p^2 = 13$, $p = .004$, 95% CI [.20, .48], and a non-significant main effect of shift, $F_{(1,60)} = 2.06$, $\eta_p^2 = .03$, $p = .156$, 95% CI [NA .13]. The main effect of cue type interacted with certainty, $F_{(1,60)} = 21.89$, $\eta_p^2 = .27$, $p < .001$, 95% CI [.12, .40], and trial block, $F_{(1,60)} = 3.99$, $\eta_p^2 = .06$, $p < .001$, 95% CI [NA, .18]. There were also three-way interactions between cue type × trial block × shift, $F_{(6.06,363.78)} = 3.30$, $\eta_p^2 = .05$, $p = .002$, 95% CI [.00, .08], and cue type × trial block × certainty, $F_{(6.06,363.78)} = 2.15$, $\eta_p^2 = .04$, $p = .047$, 95% CI [.00, .06]. No other interactions were significant, although the interaction between trial block and certainty approached significance, $F_{(6.06,363.78)} = 1.98$, $\eta_p^2 = .09$, $p = .075$, 95% CI [.00, .05]. Simple main effects analysis of the interaction between cue type and certainty revealed a significant difference between predictive and irrelevant cues on 100% contingency trials only, $F_{(1,60)} = 15.10$, $\eta_p^2 = .201$, $p < .001$, 95% CI [.07, .34], with predictive cues attracting a larger proportion of dwell time. Simple main effects analysis of the interaction between cue type, trial block and certainty revealed a significant difference between predictive and irrelevant cues from trial blocks 2-8 in the 100% contingency conditions only, smallest, $F_{(1,60)} = 4.27$, $\eta_p^2 = .07$, $p = .04$, 95% CI [NA, .16], with predictive cues always attracting a larger proportion of dwell time.

A four-way mixed ANOVA of dwell time in Stage 2 with the within factors of cue type (predictive vs. irrelevant) and trial block (1-8), and between-factors of shift (congruent vs. incongruent) and certainty (100% vs. 75%) revealed a significant main effect of cue type, $F_{(1,60)} = 24.79$, $\eta_p^2 = .29$, $p < .001$, 95% CI [.14, .42], a non-significant main effect of trial block, $F_{(5.81,364.16)} = 1.71$, $\eta_p^2 = .03$, $p = .105$, 95% CI [NA, .04], shift, $F_{(1,60)} = .00$, $\eta_p^2 = .00$, $p = .985$, 95% CI [NA, NA], and certainty, $F_{(1,60)}$ 1.81, $\eta_p^2 = .03$, $p = .183$, 95% CI [NA, .13]. The main effect of cue type interacted with certainty, $F_{(1,60)} = 34.33$, $\eta_p^2 = .36$, $p < .001$, 95% CI [.20, .49], and trial block, $F_{(6.07,364.16)} = 2.78$, $\eta_p^2 = .44$, $p = .008$, 95% CI [.01, .07]. No other interactions were significant, although the interaction between trial block, shift and certainty approached significance, $F_{(5.81,364.16)} = 2.07$, $\eta_p^2 = .03$, $p = .072$, 95% CI [NA, .05]. Simple main effects analysis of the interaction between cue type and certainty revealed a significant difference between predictive and irrelevant cues on 100% contingency trials only, $F_{(1,60)} = 58.74$, $\eta_p^2 = .50$, $p < .001$, 95% CI [.34, .60], with predictive cues attracting a larger proportion of dwell time. Simple main effects analysis of the interaction between cue type and trial block revealed a significant difference between predictive and irrelevant cues across all conditions from trial block 1-8, smallest, $F_{(1,60)} = 7.21$, $\eta_p^2 = .11$, $p = .009$, 95% CI [.02, .24], with predictive cues always attracting a larger proportion of dwell time.

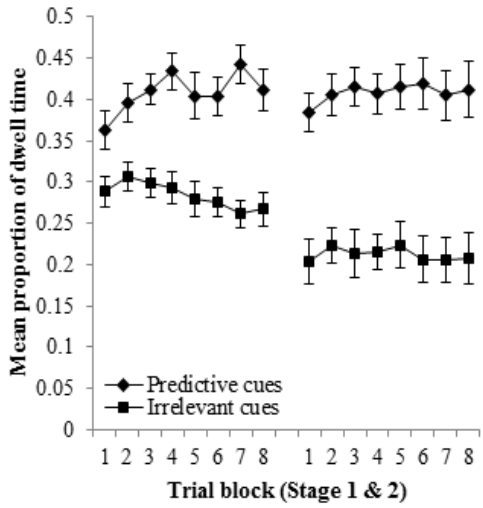


Figure 3.11a *Congruent 100% condition*

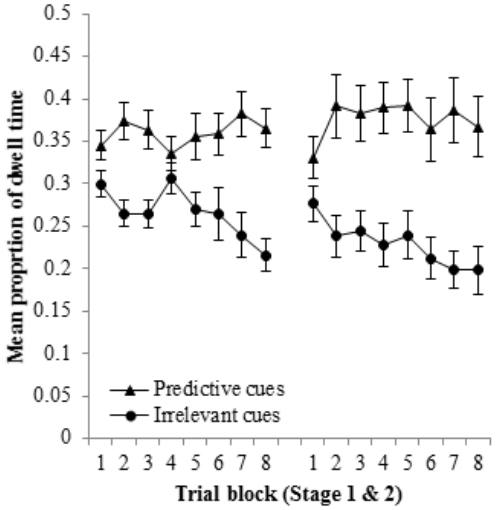


Figure 3.11b *Incongruent 100% condition*

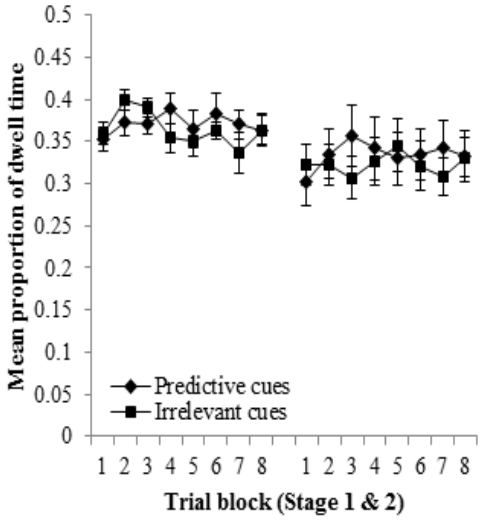


Figure 3.11c *Congruent 75% condition*

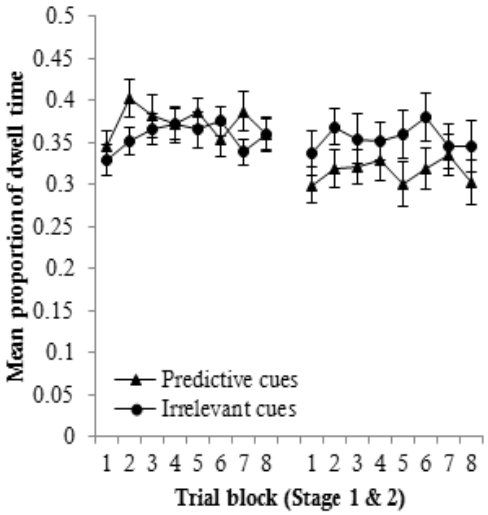


Figure 3.11d *Incongruent 75% condition*

Figures 3.11 *Data from all conditions plotted across eight trial blocks in Stage 1 and 2 shows the mean proportion of dwell time directed towards predictive and irrelevant cues in Congruent and Incongruent conditions*

3.2.2.3 *Trials following congruent and incongruent shift*

On the basis of the results of the previous experiment, it was anticipated that any differences in dwell time towards the predictive and irrelevant cues in the congruent and incongruent conditions would be most apparent at the outset

of Stage 2. Figure 3.12a and 3.12b demonstrate that the mean proportion of dwell time directed towards predictive cues in the first nine trials during Stage 2 on congruent100% and incongruent100% conditions increased at the expense of irrelevant cues. Figure 3.12c and 3.12d show that there is no clear difference between the proportion of dwell time directed towards predictive and irrelevant cues in the first nine trials during Stage 2 on congruent75% and incongruent75% conditions.

A four-way mixed measures ANOVA of proportion of dwell time with the within-factors of cue type (predictive vs. irrelevant) and three-trial block (1-3), and the between factors of shift (congruent vs. incongruent) and certainty (100% vs. 75%) revealed a significant main effect of cue type, $F_{(1,179)} = 6.59$, $\eta_p^2 = .04$, $p = .011$, 95% CI [NA, .37], trial bin, $F_{(1,179)} = 4.54$, $\eta_p^2 = .05$, $p = .012$, 95% CI [.00, .07], and shift, $F_{(1,179)} = 5.78$, $\eta_p^2 = .03$, $p = .017$, 95% CI [NA, .53], and a non-significant main effect of certainty, $F_{(1,179)} = .000$, $\eta_p^2 = .05$, $p = .992$, 95% CI [.01, .09]. The main effect of cue type interacted with shift, certainty, and trial bin, smallest $F_{(1,179)} = 3.59$, $\eta_p^2 = .04$, $p = .030$, 95% CI [NA, .06]. There was also a significant three-way interaction between cue type × shift × certainty and cue type × certainty × trial bin, $F_{(1,179)} = 4.77$, $\eta_p^2 = .05$, $p = .010$, 95% CI [.00, .08]. No other interactions were significant, smallest, Fs ≤ 2.13, Ps ≥ .12. Simple main effects analysis of the interaction between cue type × shift × certainty revealed a significant difference between predictive and irrelevant cues on congruent100% contingency trials only, $F_{(1,179)} = 28.75$, $\eta_p^2 = .138$, $p < .001$, 95% CI [.84, .89]. Simple main effects analysis of the interaction between cue type × certainty × trial bin revealed a significant difference between predictive and irrelevant cues

during the 100% contingency trials on trial block 3 (trials 7, 8 & 9), $F_{(1,179)} = 26.61$, $\eta_p^2 = .13$, $p < .001$, 95% CI [.02, .14], and a trend-level difference between predictive and irrelevant cues during 100% contingency conditions on trial bin 2 (trials 4, 5 & 6), $F_{(1,179)} = 3.73$, $\eta_p^2 = .02$, $p = .055$, 95% CI [NA, .07].

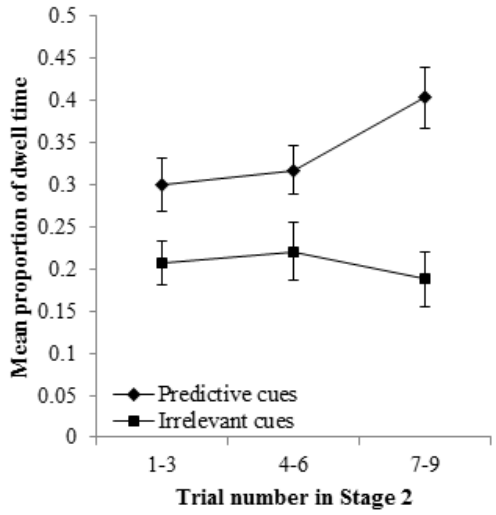


Figure 3.12a *Congruent 100% condition*

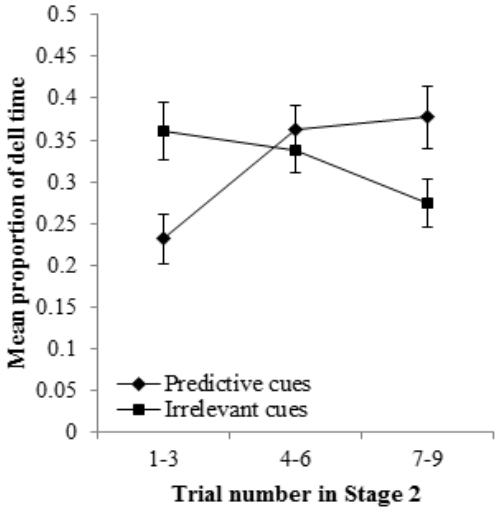


Figure 3.12b *Incongruent 100% condition*

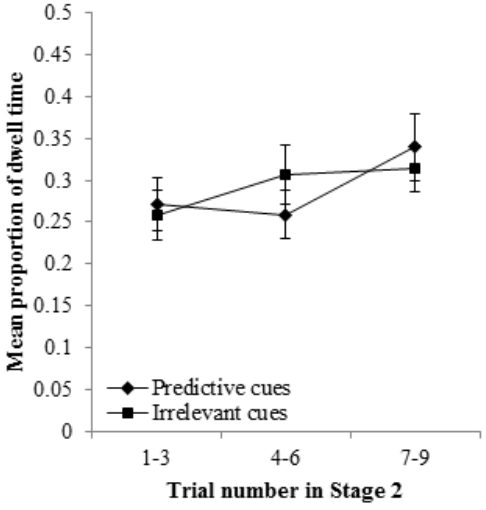


Figure 3.12c *Congruent 75% condition*

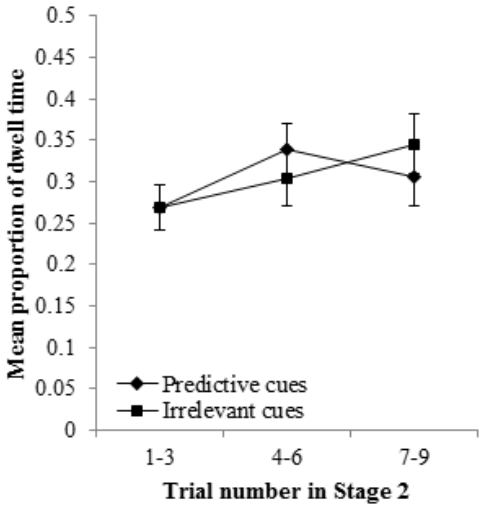


Figure 3.12d *Incongruent 75% condition*

Figures 3.12 *Data from all conditions were plotted across the first nine trials in Stage 2 and shows the mean proportion of dwell time directed towards predictive and irrelevant cues in Congruent and Incongruent conditions*

3.2.3 **Discussion**

In both Stage 1 and 2 of the current study, participants' dwell times were longer towards predictive cues than irrelevant cues for the congruent100% and incongruent100% conditions. No differences were found between the amount of dwell time directed towards predictive and irrelevant cues in the congruent75% and incongruent75% conditions.

During Stage 1, accuracy increased rapidly during the congruent100% and incongruent100% conditions, reaching 91% in both. However, in the congruent75% and incongruent75% conditions, accuracy only reached 68% and 70% respectively. Although it was expected that a lower accuracy would be reported in the 75% contingency conditions because the maximum accuracy that could be achieved was only 75%. It appeared that participants utilised a maximising strategy in which the individual consistently selects the outcome with the best chance of occurring because in trial block 8 on Stage 2 their accuracy was 70% and 72% respectively. If participants had utilised a probability matching strategy in which they matched their selections to the probability of each outcome occurring, then their accuracy would have been around 56% (75% of 75%). Accuracy fell at the outset of Stage 2, but this reduction was largest during the incongruent75% condition suggesting that participants were more affected by the incongruent shift during the 75% contingency condition compared to the 100% contingency condition.

RT decreased dramatically from trial block 1 in all conditions; although, it should be noted that the difference in RT between the congruent100% and incongruent100% conditions in Stage 1 was unexpected since they were solving

the same discrimination with similar accuracy, and most likely arose from individual differences between the groups. RT also increased at the start of Stage 2, but an explanation for this could have been that participants were reading text on the screen, including what keyboard response to make. During Stage 1 and 2, RT was faster towards the 100% contingency conditions than the 75% contingency conditions and this difference most likely reflects participant's certainty about the outcome. Another explanation could be that participants were spending longer looking at the complex pattern trying to figure out why they sometimes predicted the outcome inaccurately.

A larger proportion of dwell time was directed towards predictive cues compared to irrelevant cues during the congruent100% and incongruent100% conditions in Stage 1 and 2. However, there was no difference in the proportion of dwell time directed towards predictive and irrelevant cues in the congruent75% and incongruent75% conditions. This finding was unexpected since Figure 3.10a shows that participants had learned the predictive contingencies well enough for them to predict the outcome at a higher than chance level from block 1 onwards. Unfortunately, this meant that we were unable to test Beesley et al.'s (2005) prediction, that only attentional bias acquired via the Mackintosh (1975) mechanism can transfer into novel contexts. However, we can conclude that there is no evidence for a Pearce-Hall type effect as demonstrated in Beesley et al. (2015). Also, the fact that there was no difference in the amount of eye gaze directed towards predictive and irrelevant cues in the 75% conditions is not in keeping with the Mackintosh (1975) model either. In these conditions the predictive cue is not a perfect predictor of the outcome but it is still better than the irrelevant cue, and participants were able to

solve the task above chance level. This suggests that maybe this level of performance is not sufficient to support learned variations in dwell time. Perhaps there is a threshold in performance that needs to be passed before overt attention is changed, and maybe this is why the changes in attention observed in Experiment 1 lagged behind changes in performance.

It was anticipated that any differences in overt attention towards predictive and irrelevant cues on congruent and incongruent conditions would be most apparent at the onset of Stage 2. Subsequently, it was revealed that a higher proportion of dwell time was directed towards predictive cues compared to irrelevant cues in the congruent100% condition on the first nine trials. However, during the incongruent100% condition this pattern was reversed for the first three trials, more attention was directed towards irrelevant cues before the attentional bias reversed. This suggests that participants generalised what they had learned during Stage 1 into Stage 2, and that participants required feedback from only three trials to shift their attention. There was no clear difference between the amount of attention directed towards predictive and irrelevant cues in the congruent75% and incongruent75% conditions.

To summarise, accuracy and RT data demonstrated that participants learned the predictive contingency in all conditions during Stage 1. There was a decrease in accuracy at the outset of Stage 2 in all conditions, but the biggest decrease was found in the incongruent75% condition. It was also found that participants directed a larger proportion of dwell time towards predictive cues compared to irrelevant cues in both stages during 100% contingency conditions, but no difference was observed in the 75% contingency conditions. This pattern of results was also echoed during the first nine trials of Stage 2 in the

congruent100% condition. Again, there was no difference between the amount of attention directed towards predictive and irrelevant cues during 75% contingency conditions.

3.3 General discussion

The purpose of Chapter 3 was to investigate two methods of detecting learned variations in associability whilst simultaneously measuring dwell time. Experiment 4 used the same outcomes in Stage 1 and 2, but they were predicted by different compound cues. Experiment 5 used the same compound cues in Stage 1 and 2, but they predicted different outcomes. In both experiments the compound contained elements that were more or less relevant as predictors of the outcome. Using these, Chapter 3 investigated whether the change in associability observed in an IDS/EDS experiment and a learned predictiveness task is underpinned by a shift in attention that generalises from Stage 1 into Stage 2. In Stage 1, Experiments 4 and 5 both revealed that participants developed an attentional bias towards predictive cues when the predictive contingencies were 100%. This echoes the finding in Chapter 2 and provides support for the Mackintosh (1975) model which claims that attention will increase towards the cue which is the best available predictor of reinforcement and decrease towards all other cues available on the trial. On the other hand, this attentional bias was not observed when the predictive contingency was reduced to 75% in Experiment 5. This was unexpected since participant's accuracy was above chance level and might provide further evidence for the observation in Experiment 1 that learning precedes attention.

In Stage 2, in the IDS (Experiment 4) and congruent100% conditions (Experiment 5), participants directed more attention towards predictive cues from the outset suggesting they transferred the attentional bias acquired in Stage 1 into Stage 2, even when the specific elements of the cues themselves had changed (Experiment 4). In the EDS/incongruent100% condition, participants

also transferred their attentional bias into Stage 2, meaning that initially they directed more attention towards irrelevant cues. However, this attentional bias towards irrelevant cues was only maintained for 2 or 3 trials before participants shifted their attention towards the 'new' predictive cue, which was irrelevant in Stage 1. This provides the first direct evidence that an attentional bias is created in Stage 1 which is generalised into Stage 2 at the start of the IDS/congruent and EDS/incongruent conditions. This is important because it verifies that previous studies which only measured associability (e.g. Eimas, 1966; George & Pearce, 1999; Mackintosh & Little, 1969; Oswald et al., 2001; Roberts, Robbins & Everitt, 1988; Shepp & Eimas, 1964; Shepp & Schrier, 1969) may also be accepted as reflecting an overt change in attention. However, it is worth noting that at the start of Stage 2 the amount of attention directed towards predictive cues decreased and irrelevant cues increased, suggesting that the transfer of attention, like associability, was not perfect across the context shift. Although, it could be questioned whether changing the outcome that cues are paired with constitutes a context shift.

3.4 Conclusion

Experiments 4 and 5 observed increased attention towards predictive cues compared to irrelevant cues on an IDS/EDS or Congruent/Incongruent task when the contingencies were 100%. This provides conclusive evidence that the change in associability demonstrated in the IDS/EDS effect also reflects a change in overt attention and provides support for the attentional model proposed by Mackintosh (1975). In addition, both experiments provided evidence that this attentional bias is transferred into Stage 2, although, in the EDS conditions it was only maintained for two or three trials. However, no attentional bias was found on trials where the predictive contingency was reduced to 75%.

Chapter 4:

A comparative learned predictiveness task

Attentional models of learning such as those proposed by Mackintosh (1975) and Pearce-Hall (1980) were initially proposed as non-human animal models of behaviour. As we have seen in the discussions within the previous two chapters, these models have more recently been tested in studies that have employed adult humans as participants, as a shared evolutionary lineage extending to learning mechanisms has been assumed (Lotem & Halpern, 2012). In particular, a significant amount of research which uniquely supports the Mackintosh model has come from studies using human subjects (e.g. learned predictiveness effect, see: Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al., 2012). Conversely, much of the research which provides support for the Pearce-Hall model has been found using animal subjects (see: Dickinson, Hall & Mackintosh, 1976; Haselgrove, Esber, Pearce & Jones, 2010; Kaye & Pearce, 1984; Swan & Pearce, 1988; Wilson, Boumphrey & Pearce, 1992) with only recent, relatively scant, support coming from studies involving humans (see: Beesley, Nguyen, Pearson, Le Pelley, 2015; Easdale, Le Pelley & Beesley, 2017; Griffiths, Johnson & Mitchell, 2011; Luque, Vadillo, Le Pelley & Beesley, 2017).

The role of attention in learning in human participants and animal subjects has been investigated using very different experimental methodologies. Attention in human experiments has been quantified using the amount of time that participants view cues (e.g. Le Pelley et al., 2011). Whilst memory has been investigated using questionnaires which rely on participant's explicit knowledge (e.g. Griffiths & Mitchell, 2008). In the study by Griffiths and Mitchell,

participants' recognition memory was tested by asking them whether Mr X had eaten various foods in the training phase of the experiment. On the other hand, attention and learning in rats has been measured using spontaneous exploratory activity, since rats explore novel objects longer than familiar objects (Ennaceur & Delacour, 1988). Clearly these measures are not synonymous with each other as it is possible for a rat to view an object without interacting with it. There is also a large discrepancy between the length of human and animal experiments. Human experiments usually take between 30 minutes to an hour, but rat experiments often take place over a number of days, with long delays in between learning and test. Yet despite this inconsistency, to date, there has been no back-translation of the methodology used in the learned predictiveness task into different participant types (e.g. animals or children) to determine whether it is a by-product of the testing procedure.

Previous learned predictiveness tasks required participants to predict which outcome, of multiple outcomes, would occur. However, in the real-world it is equally important for individuals to be able to learn the relationship between cues that are associated with no outcome. For example, in order to cross the road safely we need to learn that some cues are predictors of danger (cars, red man), some are irrelevant (trees, houses) and some are predictors of the absence of danger (no cars, green man). To shed light on this, it has been suggested that the predictions made by Mackintosh's model can also be applied to non-reinforced trials, with the best predictors of non-reinforcement enjoying the same enhanced attention as those of reinforcement. This prediction has also been implied to hold true for non-reinforced trials since Le Pelley (2004) incorporates the Mackintosh-mechanism into his hybrid model which applies to both

reinforced and non-reinforced trials. To date, this assumption has only been tested in one study by Dopson, Williams, Esber and Pearce (2010) where pigeons were trained to trained to discriminate AX+ and BX-, before X was involved in a subsequent discrimination where it was revealed that cues that predicted non-reinforcement attracted more attention than cues which were irrelevant. However, this study only used associability as an indirect measure of learned changes in attention.

To date, there have been no attempts to measure overt visual attention and associability towards reinforced and non-reinforced cues in non-adult humans or non-human animals. It is important for children to be able to flexibly switch their attention, as demonstrated by the Dimension Change Card Sort (DCCS) task, and it is commonly found that children get better at switching their attention as they get older (e.g. Brooks, Hanauer, Padowska, & Rosman, 2003; Frye, Zelazo & Palfai, 1995; Kirkham, Cruess, & Diamond, 2003; Perner & Lang, 2002; Towse, Redbond, Houston-Price, & Cook, 2000; Zelazo, Frye, & Rapus, 1996). Based on this finding, it might be anticipated that children would bias their attention less effectively towards predictive cues and away from irrelevant cues because they are not as good at shifting their attention as adults. Therefore, the aim of Chapter 4 was to design a simplified version of the learned predictiveness task that could be used on adults, children and animals by measuring their eye gaze towards pairs of geometric shapes that were either predictive of reinforcement, predictive of non-reinforcement or irrelevant for predicting the outcome of the trial. This would allow performance to be compared on reinforced and non-reinforced trials.

4.1 Experiment 6

Previous discrimination studies using human participants have frequently provided support for the model of associative learning proposed by Mackintosh (1975). As we have seen, in a learned predictiveness task, Le Pelley et al. (2011), for example, found that cues which were predictive of the outcome acquired a higher associability, and also more overt visual attention, than irrelevant cues.

Historically, overt attention in human and animal subjects has been tested using different experimental paradigms. However, in recent years, technological advances have meant that eye gaze can now be investigated using the same technology in both humans and animals. To date, there has been no back-translation of eye-tracking methodology, which has overwhelmingly provided support for the Mackintosh (1975) model (e.g. Le Pelley et al., 2011; Le Pelley, Mitchell, Beesley, George & Wills, 2016), into animals to examine their acquisition of attentional biases during learning. Therefore, the aim of Experiment 6 was to eye-track an animal with a high genetic similarity to humans (orangutan) during a simplified learned predictiveness task, comparable to the design employed in Experiment 1 to determine whether overt attention is distributed in a simpler manner, and which would be consistent with Mackintosh's (1975) attentional model. To do this, I temporarily joined Dr Neil Mennie's Active Vision Lab at The University of Nottingham's Malaysia Campus to work with an orangutan that he had previously been trained to wear an eye-tracker by a process of habituation.

4.1.1 **Methods**

4.1.1.1 ***Participants***

Tsunami belongs to Zoo Negara located in Kuala Lumpur, Malaysia. Tsunami was eleven-years-old at the time of testing, and is a captive-born female Sumatran orangutan (*Pongo abelii*) who prior to the experiment, had been trained to wear a portable head mounted eye-tracker through a process of habituation. During the experiment Tsunami was fed twice a day by the keepers on a diet of fruit and vegetables. Full permission was granted for her to take part in the experiment by Zoo Negara and the Wildlife Department of Malaysia.

4.1.1.2 ***Apparatus and stimuli***

The experiment was conducted in an exercise room (6 × 6 m) located at the back of the ape centre in Zoo Negara. The room had two adjacent solid concrete walls and two wire cage sides which were open to outdoors. A laptop (HP 15-ba079sa, 40 × 40 cm screen) was placed on a stool outside one of the wire cage sides. A sunshade (1.5 × 1.5 m black netting) was constructed behind the laptop in order to reduce light levels and allow the accurate location of Tsunami's eye gaze to be determined. During testing Tsunami sat approximately 30 cm from the cage wire, restrained by a visual barrier, but she could reach her hand through the cage to collect her reward.

The eye-tracker was a bespoke unit created by Positive Science LLC, New York, (http://www.positivescience.com), specifically for Tsunami (see: Figure 4.1a). Two cameras were attached to an elastic headband which was kept in place by a chin strap. One camera captured the visual scene directly in front of

her, and the other camera and infrared light emitting diode (LED) monitored the movements of her right eye using dark pupil and corneal reflection – both cameras sampled at 30 Hz (NTSC) with a resolution of 640 × 480 pixels. The eye-tracker was connected to a battery pack and transmitter which were placed into a small backpack that Tsunami wore (see Figure 4.1b). The video from the eye and scene camera (30 frames per second) were sent via the transmitter to the receiver where they were saved onto a Macbook Pro laptop running PSLiveCapture software by Positive Science.



Figure 4.1 *Tsunami wearing the* **a)** *head-mounted eye-tracker* **b)** *backpack with transmitter*

Stimuli consisted of four basic shapes (circle, square, triangle & pentagon) of equal area (30 cm^2), located 13 cm apart on a white (RGB 1,1,1) background. Stimuli were combined into compound cues that were either followed by food (grape) or no food (see: Table 4.1). In Stage 1, stimuli were randomly assigned to serve as cues predictive of food or no food cues (circle & triangle) or irrelevant cues (square & pentagon) (see: Figure 4.2). In Stage 2,

previously predictive cues (circle & triangle) were established as irrelevant, and previously irrelevant cues (square & pentagon) were established as predictive.



Figure 4.2 *Stimuli used in Experiment 6*

Table 4.1 *Experimental design of Experimental 6*

Stage	***Compound***	***Probability of reinforcement***
1	**AX**	**1**
	AY	**1**
	BX	**0**
	BY	**0**
2	**AX**	**1**
	AY	**0**
	BX	**1**
	BY	**0**

The experiment was programmed in PsychoPy (Peirce, 2007). Cue compounds were displayed on-screen for one second, and their termination was followed by either a clicker sound recording (600 ms) which triggered the delivery of a grape, or the absence of a click and the absence of a grape. The clicker sound was recorded from a clicker that Tsunami had already had paired with reward as part of her clicker training. After the termination of the stimuli, a blank white (1,1,1) screen was presented for eight seconds which served as the

inter-trial interval. Two training sessions were conducted daily, morning (11am) and afternoon (3pm), which consisted of 16 trials – half of which were reinforced.

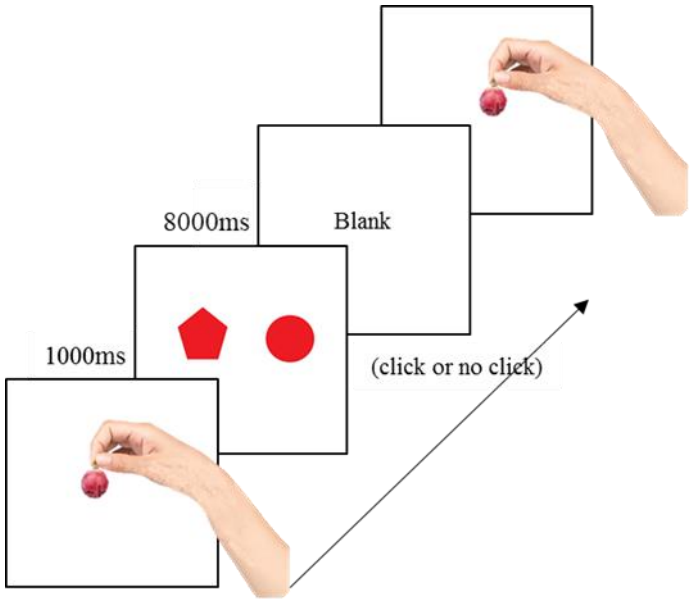


Figure 4.3 *Temporal layout of a trial during Experiment 6*

4.1.1.3 ***Procedure***

In order to calibrate the eye-tracker, Tsunami was seated 2 m from the cage bars and a 1.6 m PVC pole with a cup at the end was used to present a raisin in a variety of different spatial locations. The eye-tracker was calibrated offline using the corneal reflection generated by the infrared LED and Yarbus software. Between 4-9 calibration points were marked when Tsunami first picked up the raison because it was highly likely that she was looking in that location in order to guide her hand. After calibration was complete, a crosshair was superimposed upon the scene video to indicate eye gaze.



Figure 4.4a *Calibration procedure*



Figure 4.4b *Experimental setup from behind*

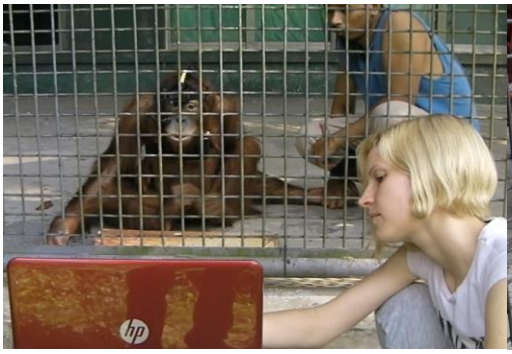


Figure 4.4c *Experimental setup from the front*

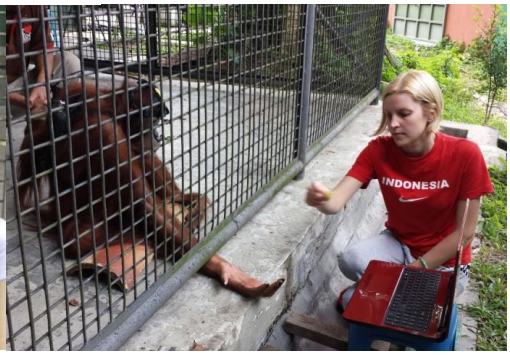


Figure 4.4d *Experimental setup from the side*

Figure 4.4 *Testing procedure during Experiment 6*

Tsunami was accompanied in the testing arena on every training session by her keeper who also attached the eye-tracking equipment onto her. After calibration, he instructed her to sit behind the barrier and held her hand throughout testing to ensure that she maintained that position. At the start of each trial her attention was captured using a grape which was moved into the centre of the laptop screen to encourage her to look at the screen approximately two seconds before the stimuli appeared. On reinforced trials (e.g. AX & AY) a clicker sound informed Tsunami that a reward was coming, and she was handed the grape by the experimenter.

4.1.1.4 *Data coding*

Eye-tracking recordings were coded manually, scored frame-by-frame. The researcher counted the number of fixations (3+ frames when the pupil was stable) that Tsunami directed into either ROI, and the duration of these fixations. To calculate dwell time (ms) the number of frames was multiplied by 33.33. Unlike experiments in previous chapters, the proportion of dwell time was not calculated since Tsunami looked at the screen for such a smaller proportion of each trial. A small amount of data were lost due to signal interference or when the eye-tracker lost track of the pupil – in total 6 trials were removed on this basis.

4.1.2 **Results**

The analysis of single case studies is still the subject of much disagreement and there remains no agreed-upon statistical method (Smith, 2012). Consequently, the results of Experiment 6 were analysed in accordance with the most similar published study, which was a head-mounted eye-tracking study on a single chimpanzee (Kano & Tomonaga, 2013).

STAGE 1

In keeping with the results of Experiments 1 to 5, conducted with adult human participants, Figure 4.5a reveals that predictive cues attracted more dwell time than irrelevant cues. A one-way repeated measures ANOVA of mean dwell time with the factor of cue type (predictive vs. irrelevant) revealed a trend-level

main effect, $F_{(1,46)} = 3.80$, $\eta_p^2 = .08$, $p = .057$, 95% CI [NA, .21]. Figure 4.5b shows that predictive cues also attracted a larger number of fixations compared to irrelevant cues. A one-way repeated measures ANOVA of mean fixation count with the factor of cue type (predictive vs. irrelevant) revealed a significant main effect, $F_{(1,69)} = 12.78$, $\eta_p^2 = .16$, $p = .001$, 95% CI [.05, .28].

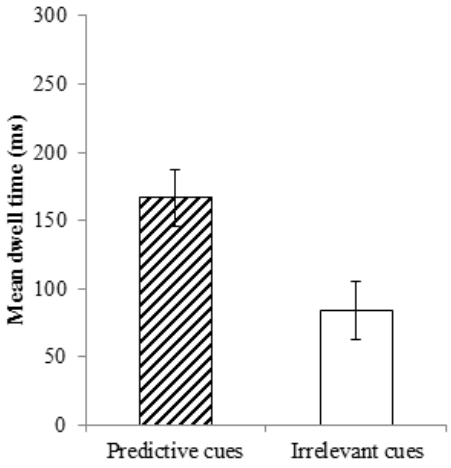


Figure 4.5a *Mean dwell time directed towards predictive and irrelevant cues during Stage 1*

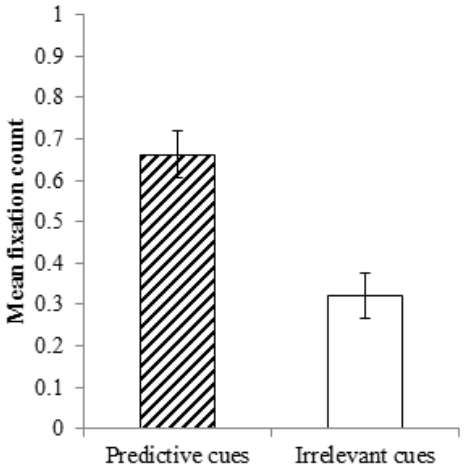


Figure 4.5b *Mean number of fixations directed towards predictive and irrelevant cues during Stage 1*

Figure 4.6a and b show the mean dwell time and number of fixations (respectively) to cues that were predicative of food, no food and to the irrelevant cues, separated by which trial type they were presented upon (food or no food). Both of these measures show predictive cues come to attract more overt attention than irrelevant cues, irrespective of whether they are predictive of food or no food. These observations were supported by a two-way repeated measures ANOVA of mean dwell time with the factors of cue type (predictive vs. irrelevant) and reinforcement (reinforced vs. non-reinforced), which revealed a

non-significant main effect of predictiveness, $F_{(1,16)} = 2.63$, $\eta_p^2 = .14$, $p = .124$, 95% CI [NA, .38], reinforcement, $F_{(1,16)} = .51$, $\eta_p^2 = .03$, $p = .512$, 95% CI [NA, .17], and a non-significant interaction, $F_{(1,16)} = .001$, $\eta_p^2 = .00$, $p = .971$, 95% CI [NA, .23]. A two-way repeated measures ANOVA of mean fixation count with the factors of cue type (predictive vs. irrelevant) and reinforcement (reinforced vs. non-reinforced) revealed a significant main effect of predictiveness, $F_{(1,29)} = 4.68$, $\eta_p^2 = .14$, $p = .039$, 95% CI [NA, .32], a non-significant main effect of reinforcement, $F_{(1,29)} = 1.00$, $\eta_p^2 = .03$, $p = .326$, 95% CI [NA, .47], and a non-significant interaction, $F_{(1,29)} = .18$, $\eta_p^2 = .01$, $p = .672$, 95% CI [NA, .25].

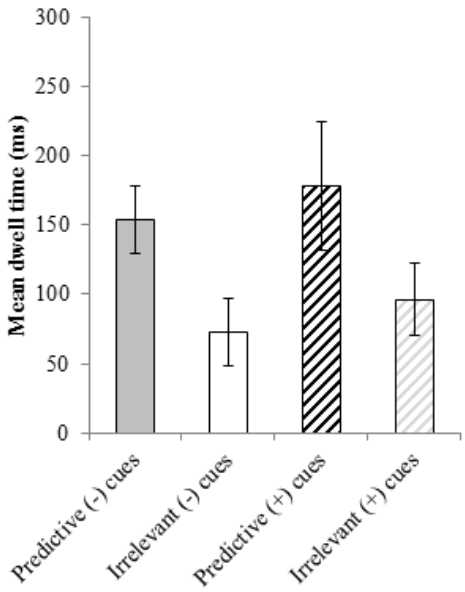


Figure 4.6a *Mean dwell time directed towards predictive and irrelevant, reinforced and non-reinforced cues during Stage 1*

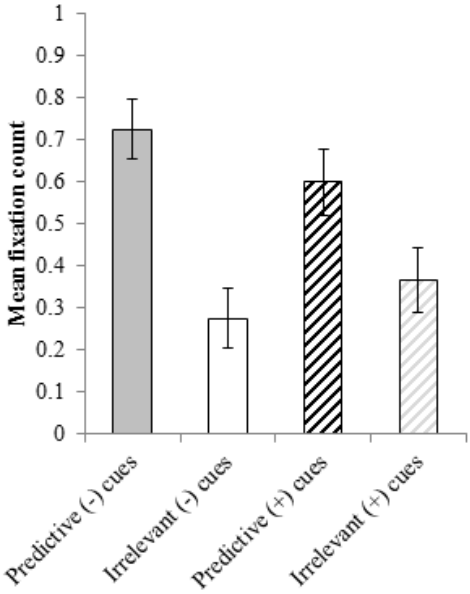


Figure 4.6b *Mean number of fixations directed towards predictive and irrelevant, reinforced and non-reinforced cues during Stage 1*

STAGE 2

After 16 training sessions, the predictive contingencies were reversed, so predictive cues in Stage 1 became irrelevant in Stage 2, and vice versa. Unfortunately, due to time constraints, research was not able to persist long after the researcher left Malaysia and only 8 training sessions were carried out in Stage 2. Figure 4.7a reveals that Tsunami directed more dwell time towards predictive cues than irrelevant cues in Stage 2. A one-way repeated measures ANOVA of mean dwell time with the factor of cue type (predictive vs. irrelevant) revealed a non-significant main effect, $F_{(1,16)} = .13$, $\eta_p^2 = .01$, $p = .719$, 95% CI [NA, .17]. Figure 4.7b shows that predictive cues also attracted a greater number of fixations compared to irrelevant cues. A one-way repeated measures ANOVA of mean fixation count with the factor of cue type (predictive vs. irrelevant) revealed a significant main effect, $F_{(1,16)} = 21.46$, $\eta_p^2 = .57$, $p < .001$, 95% CI [.25, .71].

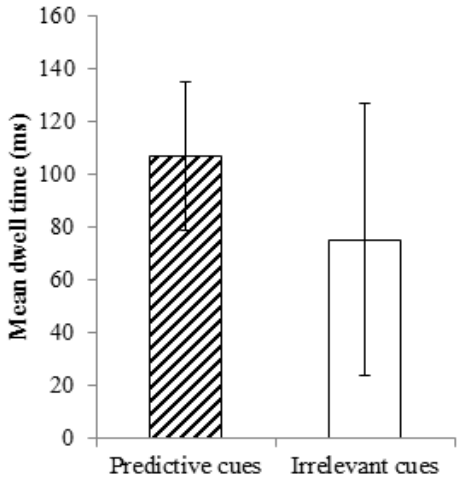


Figure 4.7a *Mean dwell time directed towards predictive and irrelevant cues during Stage 2*

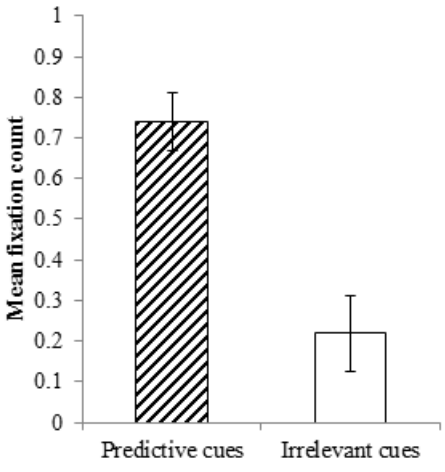


Figure 4.7b *Mean number of fixations directed towards predictive and irrelevant cues during Stage 2*

Figure 4.8a and b show the mean dwell time and number of fixations (respectively) to cues that were predicative of food, no food and to the irrelevant cues, separated by which trial type they were presented upon (food or no food). Both of these measures show that cues which were predictive of no food attracted the most overt attention, followed by cues that were predictive of food and then irrelevant cues. These observations were supported by a two-way repeated measures ANOVA of mean dwell time with the factors of cue type (predictive vs. irrelevant) and reinforcement (reinforced vs. non-reinforced) revealed a non-significant main effect of predictiveness, $F_{(1,6)} = .16$, $\eta_p^2 = .03$, $p = .705$, 95% CI [NA, .32], reinforcement, $F_{(1,6)} = .13$, $\eta_p^2 = .02$, $p = .727$, 95% CI [NA, .31], and a non-significant interaction, $F_{(1,6)} = .22$, $\eta_p^2 = .24$, $p = .224$, 95% CI [NA, .34]. A two-way repeated measures ANOVA of mean fixation count with the factors of cue type (predictive vs. irrelevant) and reinforcement (reinforced vs. non-reinforced) revealed a significant main effect of predictiveness, $F_{(1,6)} = 74.42$, $\eta_p^2 = .93$, $p < .001$, 95% CI [.68, .95], a non-significant main effect of reinforcement, $F_{(1,6)} = 1.00$, $\eta_p^2 = .14$, $p = .356$, 95% CI [NA, .47], and a non-significant interaction, $F_{(1,6)} = .71$, $\eta_p^2 = .11$, $p = .431$, 95% CI [NA, .44].

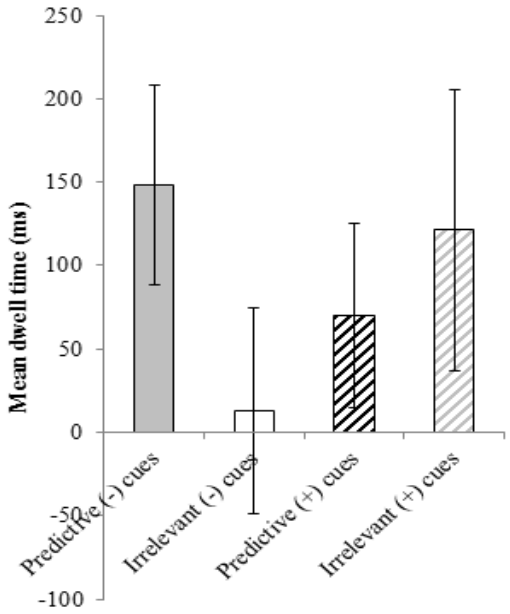


Figure 4.8a *Mean dwell time directed towards predictive and irrelevant, reinforced and non-reinforced cues in Stage 2*

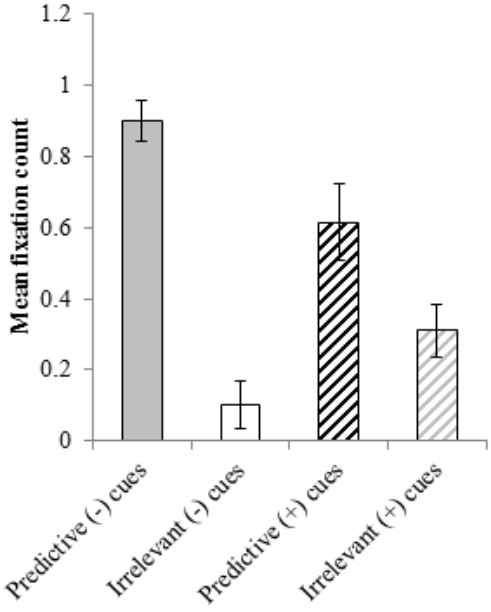


Figure 4.8b *Mean number of fixations directed towards predictive and irrelevant, reinforced and non-reinforced cues in Stage 2*

4.1.3 **Discussion**

Experiment 6 established a simplified version of the learned predictiveness task, during which shapes (presented in pairs) were either predictive of reinforcement (a grape), predictive of non-reinforcement (no grape) or irrelevant. This paradigm could be used to test various participant types, so their performance could be compared more directly. Using eye-tracking technology this task was back-translated into an orangutan to determine whether the learned predictiveness effect is a uniquely human ability. Findings revealed that Tsunami directed more attention towards predictive cues compared to irrelevant cues, as predicted by the Mackintosh (1975) model.

Overall, Tsunami directed more attention towards predictive cues compared to irrelevant cues, demonstrating that the learned predictiveness effect

is not unique to humans. However, because orangutans share a close evolutionary history with humans, it cannot be ruled out that the learned predictiveness effect is a hominid ability. In addition to this, it should be noted that the difference between the amount of eye gaze directed towards predictive and irrelevant cues was only significant when analysing fixation count, and trend-level when analysing dwell time. An explanation for this is that orangutan eye-movements are faster than human eye-movements. For example, when comparing the eye gaze patterns of great apes, Kano, Call and Tomonaga (2012), and Kano and Tomonaga (2013), revealed that they were all remarkably similar except that humans directed longer dwell times towards each area of a scene or person.

The results of this experiment permit some further theoretical consideration. Spence's (1936) theory of discrimination learning suggests that when a response is reinforced in the presence of the S+, it conditions excitatory response tendencies. On the other hand, when a response is non-reinforced, it conditions inhibitory properties which suppress the instrumental behaviour. Therefore, differential responding to a S+ and S- reflects conditioned excitation to S+ and conditioned inhibition to S-. According to this theory, if Tsunami was rewarded every time she looked at the predictive cue, then instrumental conditioning would mean this behaviour would be more likely to be repeated in the future. Conversely, if the omission of a grape was perceived as negative punishment, then inhibitory conditioning would mean that Tsunami should have looked less at predictive cues on non-reinforced trials, but this was not observed. However, a saccade made towards a predictive cue is also a saccade away from an irrelevant cue and this will be rewarded on 50% of all trials, which

may be sufficient to instrumentally condition this response on the non-reinforced trials too. Thus, Tsunami was not looking at cues that were predictive of non-reinforcement, instead she was looking away from irrelevant cues.

4.2 Experiment 7

Even within species, the range of participants tested in the existing learned predictiveness effect literature has been limited, only testing adult human participants – in particular undergraduate students (e.g. Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al., 2012). However, there are benefits to broadening this scope; for example, children can be viewed as poor learners owing to their limited experience.

Being able to stabilise and flexibility shift attention towards a goal is an ability that is developed from infancy to adolescence (Best & Miller, 2010; Garon, Bryson & Smith, 2008). It isn't until soon before children start attending school that they show a robust ability to flexibly shift their attention, and this is often measured using the Dimension-Change Card-Soft (DCCS) task (Frye, Zelazo & Palfai, 1995). During the DCCS task, in Stage 1 children are required to sort cards into two groups depending on one dimension (e.g. shape). Then in Stage 2, children are asked to sort the cards according to a previously irrelevant dimension (e.g. colour) – essentially performing an EDS. Findings have revealed that 88% of five-year-old children are able to accurately perform the shift, compared with only 41% of three-year-old children (Doebel & Zelazo, 2015). This has even been investigated using eye-tracking methodology by Chevalier, Blaye, Dufau and Lucenet (2010) who found that the pattern of fixations individuals directed towards the predictive or irrelevant dimensions of a stimulus was modulated by age.

The aim of Experiment 7 was to determine whether children demonstrated the learned predictiveness effect, and if an attentional bias towards predictive cues and away from irrelevant cues was stronger in older children than younger children. Experiment 7 employed a similar paradigm to Experiment 6 so that performance could be compared more directly.

4.2.1 **Methods**

4.2.1.1 ***Participants***

Sixty-nine children, who attended the University of Nottingham, School of Psychology public engagement event "Spring Scientist Week" participated in return for tokens. The sample consisted of 33 females (Mean ± SD: 8.70 ± 4.751). Exclusion criteria included learning disabilities or conditions triggered by flashing lights (e.g. epilepsy).

4.2.1.2 ***Apparatus and stimuli***

The experiment was programmed in PsychoPy and displayed on a Tobii TX300 eye-tracker using additional python code. The eye-tracker recorded eye movements from both eyes at a rate of 120 Hz, and determined the location of gaze by monitoring the position of the pupil using an infrared camera mounted on the front of the display monitor. Stimuli were presented on a 50.9 × 28.6 cm screen with the resolution set to 1080 × 9120. Participants viewed stimuli binocularly, unrestrained, from an average distance of 60 cm.

Stimuli consisted of four basic shapes (circle, square, triangle & pentagon) (see: Figure 4.9) of equal area (30 cm), located 13 cm apart on a white

(1,1,1) background. Regions of interest were set to 7 × 7 cm squares around the shapes, and stimuli subtended a visual angle of 28.07°. Stimuli were randomly assigned to serve as cues A, B, X or Y (see Table 4.2). Stimuli that served as predictive cues (A & B) were counterbalanced with the stimuli that served as irrelevant cues (X & Y) (see Appendix 6 for full counterbalancing).

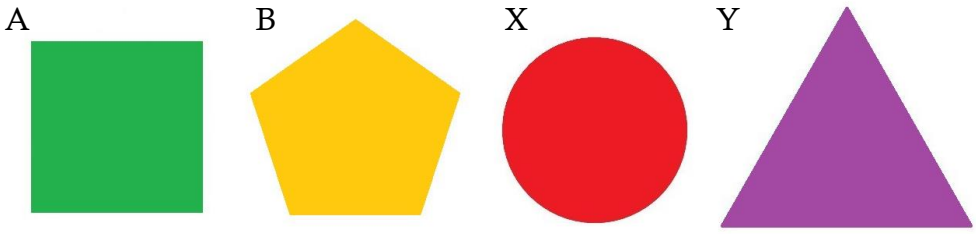


Figure 4.9 *Stimuli used in Experiment 7*

Table 4.2 *Experimental design for Experiment 7*

Compound	***Probability of reinforcement***
AX	**1**
AY	**1**
BX	**0**
BY	**0**

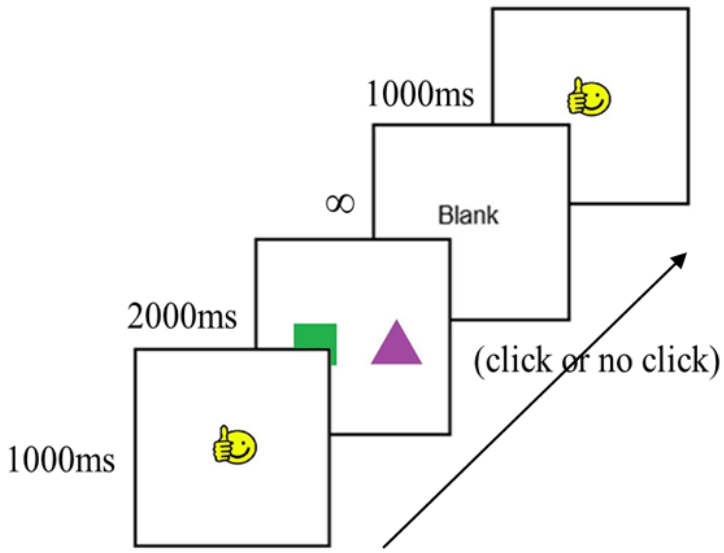


Figure 4.10 *Temporal layout for a trial in Experiment 7*

4.2.1.3 ***Procedure***

The eye-tracker was calibrated for each participant at the outset of the experimental session using a five-point calibration, except for one participant for which calibration failed. At the start of each experimental session, the experimenter checked that both pupils were detected. The researcher also altered the angle of the screen depending on the height of the child, and ensured that they were seated 60 cm away from the screen.

At the start of each trial a smiley face was displayed for one second to capture the child's attention and act as a fixation point to ensure that they were not accidently looking in either region of interest when the cues appeared. Cue compounds were displayed on-screen for two seconds, during which time children were encouraged to make a prediction about whether they thought it would be a 'grape' or 'no grape' trial, and their termination was either followed

by a clicker recording (AX & AY), after which children could take a slice of grape, or the absence of the click (BX & BY), after which children were *not* permitted to take a slice of grape. After the offset of stimuli, a blank white screen was presented until the child had eaten the grape, and the experimenter pressed the spacebar on the keyboard to start the next trial.

Verbal instructions to the children were: "*In this game you will see two shapes, one here* (pointed to screen) *and one here* (pointed to screen). *Your task is to work out whether you will get a grape or not by looking at the shapes. Some shapes may be more helpful than others. If you hear a click sound that means that you get a grape, and if you like grapes you can take a piece and eat it.* If a child said they did not like grapes they were told: *"That's okay, you can just collect them. You need to try and guess when the shapes are on the screen, before you hear the sound, because I will count how many correct guesses you make. If you do really well you might get on the leader board, but before that there is going to be a black dot on the screen and you need to follow this with your eyes. Are you ready?*"

Trial order was randomised over the whole experiment (32 trials), including 16 reinforced trials and 16 non-reinforced trials. Each of the four compounds was presented 8 times, with all cues presented an equal number of times on the left and the right-hand side of the screen. The experiment was paced by the experimenter who needed to press the spacebar to start the next trial to give children enough time to eat the slice of grape on reinforced trials and sit back in the chair so that the eye-tracker could detect their pupils. Upon completion, all children were told that they had done a 'great job', received one token and given a sticker.

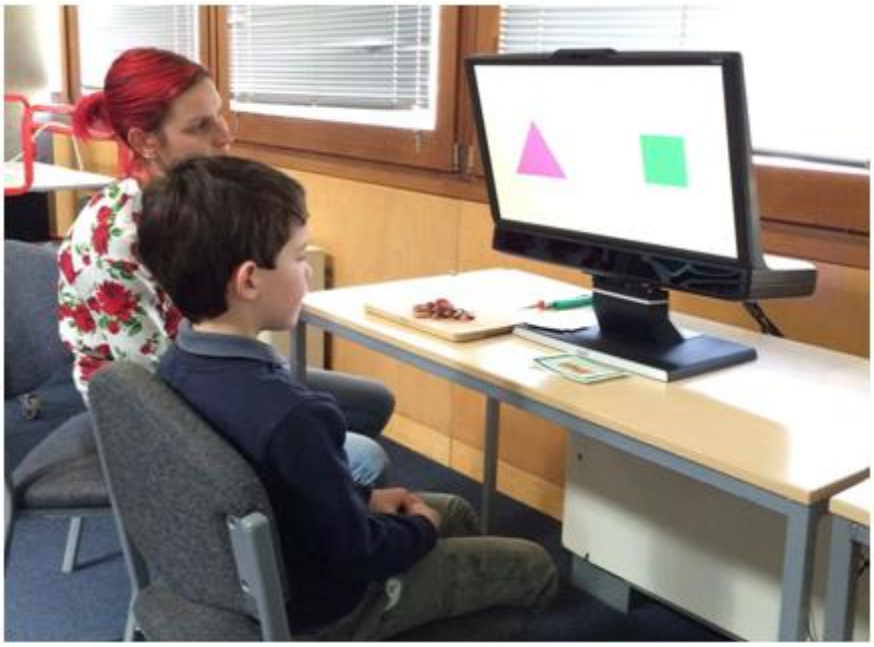


Figure 4.11 *Experimental setup for Experiment 7*

4.2.2 **Results**

On each trial children were asked to predict whether they would receive a grape or not when the shapes were on the screen by saying ‘grape’ or ‘no grape’. However, not all children made predictions. Therefore, the analysis was divided into three groups: those who made predictions and had high accuracy (above chance), those that made predictions and had low accuracy (chance level or below) and children that did not make overt predictions. For subsequent analysis Greenhouse-Geisser corrections were applied where sphericity was violated.

4.2.2.1 *Behavioural data*

The mean number of correct trials for the high and low accuracy groups are shown in Figure 4.12. This reveals that participants in the high accuracy group learned the predictive contingency because the mean accuracy was 22.59, which a one-sample t-test reported was significantly above chance (16), $t_{(27)} = 9.04$, $p < .001$. However, participants in the low accuracy group clearly did not learn the predictive relationship because the mean accuracy was 13.47, which a one-sample t-test reported was significantly below chance (16), $t_{(14)} = 3.71$, $p = .002$.

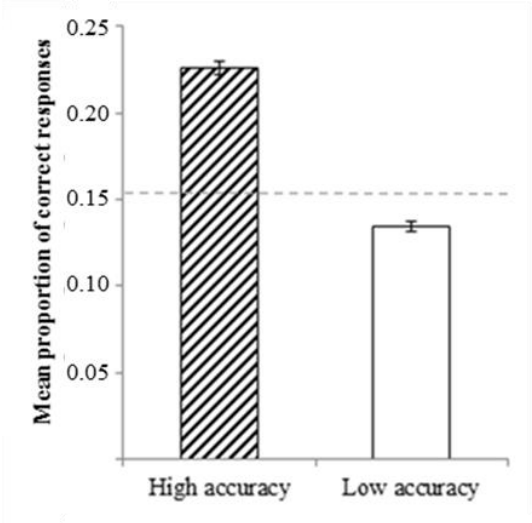


Figure 4.12 *The mean accuracy of participants in low and high accuracy groups*

4.2.2.2 *Eye gaze analysis*

A count was created based on the screen refresh rate (approx. 60 Hz). To calculate dwell time (ms) the length of each trial (2,000 ms) was multiplied by

the screen refresh rate, then divided by the total number of screen refreshes in two seconds and multiplied by 1000 (see Equation 4.1).

$$Dwell\ time\ (ms) = \frac{2 \times Screen\ refresh\ rate}{120} \times 1000 \qquad \textbf{Equation 4.1}$$

The mean amount of dwell time that participants with > chance accuracy directed towards predictive and irrelevant cues is shown in Figure 4.13a, which reveals that predictive cues attracted more dwell time compared to irrelevant cues. A one-way repeated measures ANOVA of dwell time with the factor of cue type (predictive vs. irrelevant) revealed a significant main effect, $F_{(1,27)}$ = 6.13, η_p^2 = .19, p = .020, 95% CI [.02, .38]. Figure 4.13b reveals that for participants with ≤ chance accuracy, irrelevant cues attracted slightly more dwell time compared to predictive cues. A one-way repeated measures ANOVA of dwell time with the factor of cue type (predictive vs. irrelevant) revealed a non-significant main effect, $F_{(1,14)}$ = .39, η_p^2 = .03, p = .543, 95% CI [NA, .24].

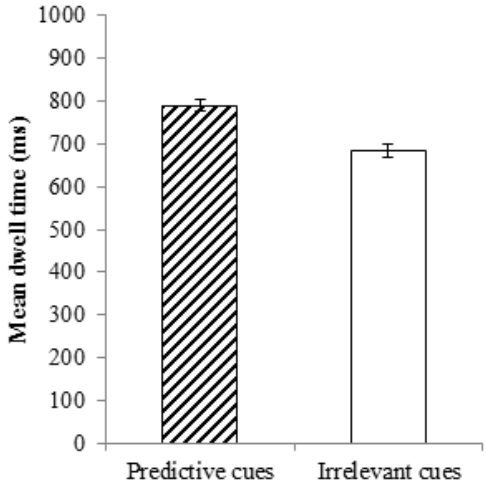


Figure 4.13a *Mean dwell time directed towards predictive and irrelevant cues in the high accuracy group*

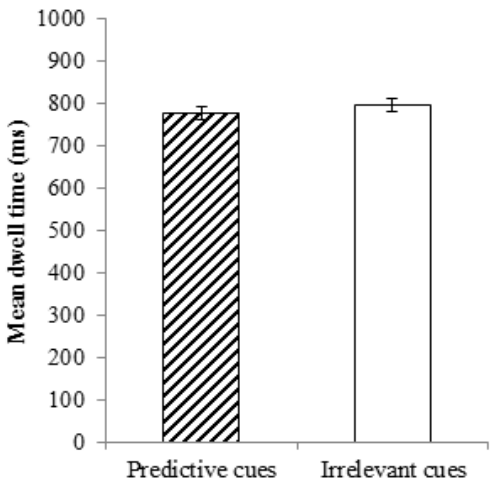


Figure 4.13b *Mean dwell time directed towards predictive and irrelevant cues in the low accuracy group*

Figure 4.14a reveals that in the high accuracy group, dwell time towards predictive cues was longer than irrelevant cues (irrespective of trial type); however, there was little evidence for any differences in dwell time towards predictive or irrelevant cues in the low accuracy group. A two-way repeated measures ANOVA of dwell time with the factors of cue type (predictive vs. irrelevant) and reinforcement (reinforced vs. non-reinforced) revealed a significant main effect of predictiveness, $F_{(1,27)} = 6.19$, $\eta_p^2 = .19$, $p = .019$, 95% CI [.02, .38], a non-significant main effect of reinforcement, $F_{(1,27)} = .50$, $\eta_p^2 = .02$, $p = .486$, 95% CI [NA, .16], and a non-significant interaction, $F_{(1,27)} = .44$, $\eta_p^2 = .02$, $p = .514$, 95% CI [NA, .15]. Figure 4.16b reveals that in the low accuracy group, predictive reinforced cues attracted the most dwell time, followed by predictive non-reinforced cues, irrelevant cues presented on reinforced trials, and finally, irrelevant cues presented on non-reinforced trials. A two-way repeated measures ANOVA of dwell time with the factors of cue type (predictive vs. irrelevant) and reinforcement (reinforced vs. non-reinforced) revealed a non-significant main effect of predictiveness, $F_{(1,14)} = .39$, $\eta_p^2 = .03$, $p = .544$, 95% CI [NA, .24], a non-significant main effect of reinforcement, $F_{(1,14)} = .03$, $\eta_p^2 = .002$, $p = .865$, 95% CI [NA, .11], and a non-significant interaction, $F_{(1,14)} = .51$, $\eta_p^2 = .04$, $p = .488$, 95% CI [NA, .26].

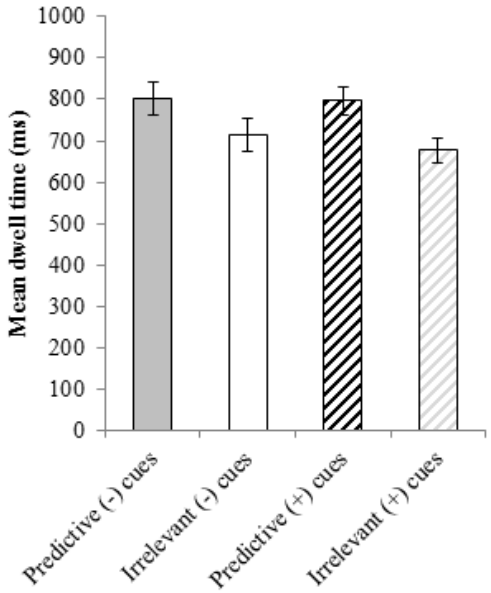


Figure 4.14a *Mean dwell time directed towards predictive reinforced, predictive non-reinforced, irrelevant reinforced and irrelevant non-reinforced cues in the high accuracy group*

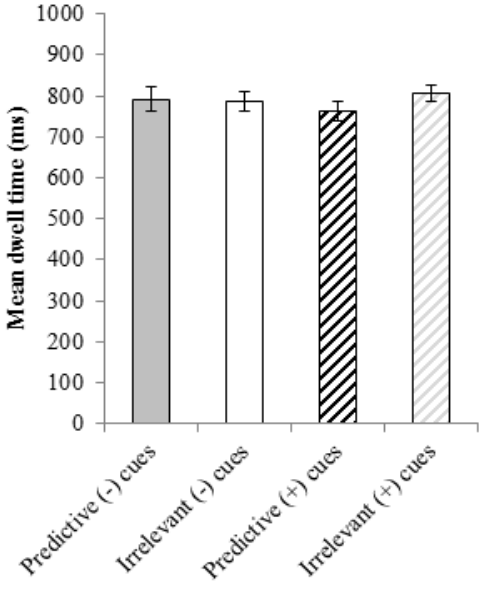


Figure 4.14b *Mean dwell time directed towards predictive reinforced, predictive non-reinforced, irrelevant reinforced and irrelevant non-reinforced cues in the low accuracy group*

4.2.3 **Discussion**

Experiment 7 examined whether children would learn to direct more overt attention to a cue that was predictive of an outcome than an irrelevant cue, an effect demonstrated previously in adults (see: Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al., 2012). Analysis revealed that children in the high accuracy group (who had learned the predictive contingency) directed more dwell time towards predictive cues compared to irrelevant cues, therefore demonstrating the learned predictiveness effect. No difference was observed between the amount of dwell time directed towards predictive and irrelevant cues in the low accuracy group, in fact, children

directed slightly more attention towards irrelevant cues which might explain why they failed to learn the predictive contingencies – or vice versa.

The Mackintosh (1975) model predicts that attention will be highest towards the cue that is the best available predictor of reinforcement available on a trial. This prediction has also been implied to hold true for non-reinforced trials since Le Pelley (2004) incorporated a general Mackintosh-mechanism into his hybrid model which applies, more formally, to both reinforced and non-reinforced trials. The findings of Experiment 7 revealed an attentional bias towards predictive cues on both reinforced and non-reinforced trials, which is consistent with the generalised attentional rule.

4.3 Experiment 8

Despite the clear evolutionary advantage of individuals being able to learn cue → no outcome relationships within their environment, existing learned predictiveness studies have only investigated adult humans' ability to learn cue → outcome relationships (e.g. Le Pelley & McLaren, 2003). In fact, the amount of attention attracted by cues which were predictive of reinforcement compared to cues that were predictive of non-reinforcement has only been investigated in one study in pigeons by Dopsen et al. (2010). Therefore, the aim of Experiment 8 was to use the same learned predictiveness task used in Experiments 6 and 7 to investigate differences in the amount of attention adult humans directed towards predictive and irrelevant cues on reinforced and non-reinforced trials, and to provide a performance comparison for the orangutan and children.

4.3.1 **Methods**

4.3.1.1 ***Participants***

Nineteen undergraduate or postgraduate students from The University of Nottingham participated in return for course credit or a payment of £2. The sample consisted of 8 females (Mean ± SD: 25.38 ± 5.68). Exclusion criteria were the same as in previous experiments.

4.3.1.2 ***Apparatus and stimuli***

Experiment 8 was programmed in Experiment Builder and run on a Eyelink1000 Plus eye-tracker. Stimuli consisted of four basic shapes (circle,

square, triangle & pentagon) of equal area (30 cm), and regions of interest were set to the exact size of the shapes. Stimuli were presented on a 33 × 57 cm BenQ XL2420T LED monitor with resolution set to 1920 × 1080 at 114Hz, located 13 cm apart on a white (1,1,1) background (see Figure 4.15). Stimuli were viewed from 67 cm away, restrained by a chin and forehead rest, and stimuli subtended a visual angle of 25.24°. Stimuli were randomly assigned to serve as stimuli A, B, X or Y (see Table 4.3). Stimuli that served as predictive cues (A & B) were counterbalanced with stimuli that served as irrelevant cues (X & Y) (see Appendix 6 for full counterbalancing).

Table 4.3 *Experimental design for Experiment 8*

Compound	***Probability of reinforcement***
AX	**1**
AY	**1**
BX	**0**
BY	**0**

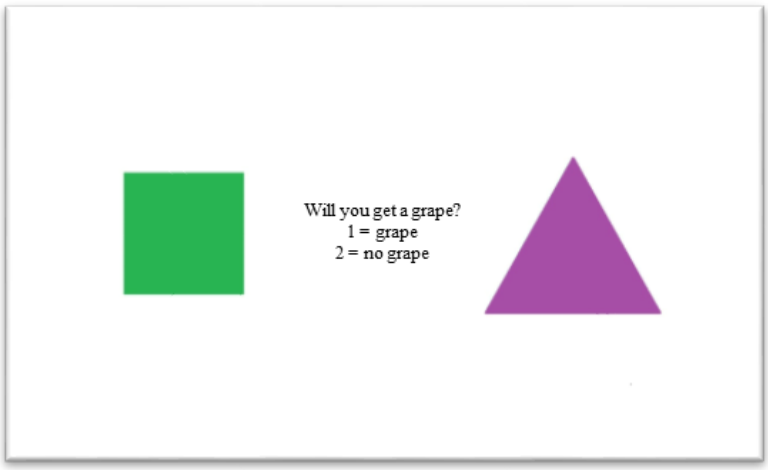


Figure 4.15 *Spatial layout for trials during Experiment 8*

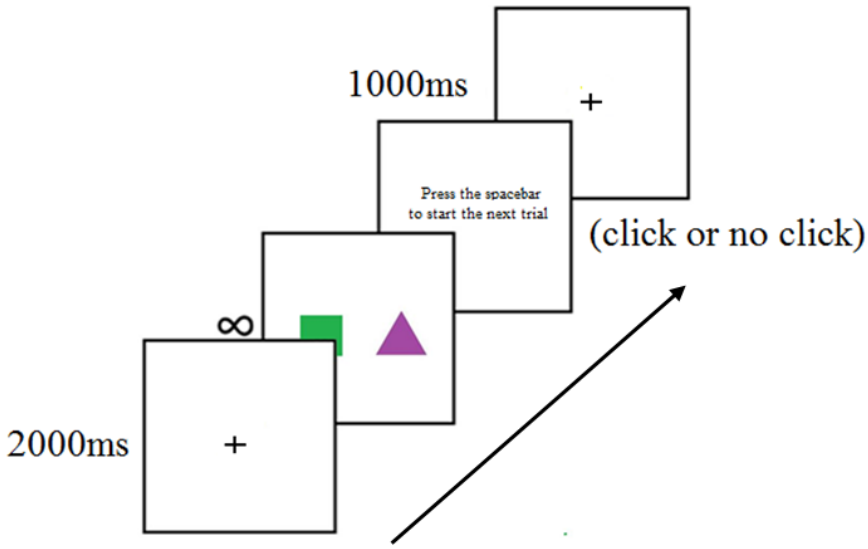


Figure 4.16 *Temporal layout of a trial during Experiment 8*

4.3.1.3 ***Procedure***

The eye-tracker was calibrated for each participant at the outset of the experimental session using a nine-point calibration. A brief health questionnaire was administered to screen for exclusion criteria, written and verbal instructions

were given and informed consent was gained. At the start of each experimental session, the experimenter checked that both pupil and corneal reflections were present whilst participants read the on-screen instructions before performing a calibration.

At the start of each trial a fixation cross was displayed for 1000 ms to ensure that participants were not accidently looking into either ROI when the cues appeared. Cue compounds were displayed until participants made a prediction about the trial outcome (1 = grape; 2 = no grape). After this, a blank white screen was presented for 1000 ms during which participants heard either a clicker sound recording or nothing. If they heard the clicker sound, participants were instructed to take a slice of grape and eat it, before pressing the space bar to begin the next trial. If they heard nothing, participants could press the space bar to start the next trial immediately.

Written instructions: *"Each trial will begin with a fixation cross in the centre of the screen which you need to look at. Then, two shapes will appear and you need to predict whether you will get a grape or not. At first you will need to guess but later you might be able to use the shapes to help you."*

Verbal instructions: *"You will see two coloured shapes on the screen at the same time and your task is to decide, based on these, whether you will get a grape piece or not. If you think that you are going to get a grape then you need to press number 1 on the keyboard, if you don't think that you will then you need to press number 2. After you make a selection the screen will go blank for one second in which time you need to listen for a click sound. If you hear the click that means that you can take and eat a piece of grape, but if there's no click then you should hit the space bar to start the next trial."*

Trial order was randomised over the whole experiment (32 trials), including 16 reinforced trials and 16 non-reinforced trials. All four compounds were presented 8 times, with each cue presented an equal number of times on the left and the right-hand side of the screen. The experiment was self-paced, giving participants enough time to eat a piece of grape on the reinforced trials. Upon completion participants were thanked for their time and debriefed.

4.3.2 **Results**

4.3.2.1 ***Behavioural data***

The mean number of correct trials increased, reaching 7.38 on trial block 8 (see Figure 4.17a), which a one-sample t-test revealed was significantly above chance (50%), $t_{(15)} = 1115.17$, $p < .001$. A one-way repeated measures ANOVA of the mean number of correct with the factor of trial block (1-8) revealed a significant main effect, $F_{(3.78, 56.80)} = 8.81$, $\eta_p^2 = .37$, $p < .001$, 95% CI [3.78, 56.8]. Figure 4.17b shows that RT decreased across trial blocks as training progressed. A one-way repeated measures ANOVA of RT with the factor of trial block (1-8) revealed a significant main effect, $F_{(3.42,51.37)} = 7.17$, $\eta_p^2 = .32$, $p < .001$, 95% CI [.12, .43].

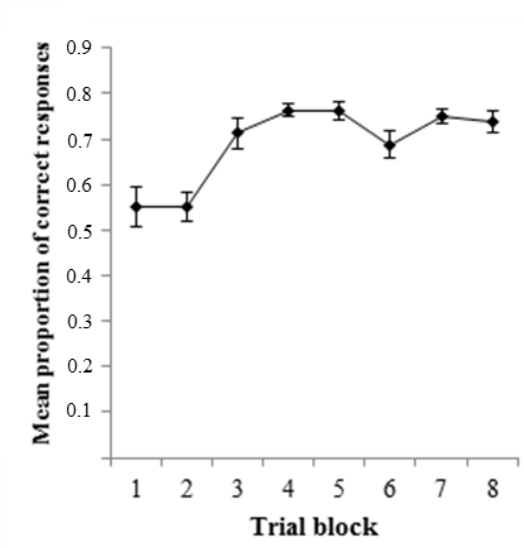


Figure 4.17a *Mean proportion of correct trials across trial blocks*

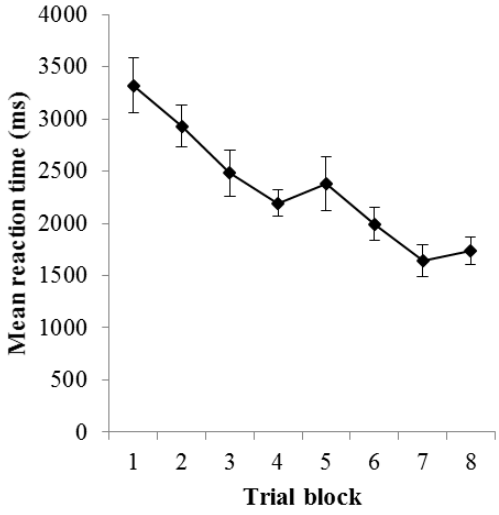


Figure 4.17b *Mean RT across trial blocks*

4.3.2.2 *Eye gaze analysis*

Figure 4.18a reveals that predictive cues attracted more dwell time than irrelevant cues over the whole experiment. However, a one-way repeated measures ANOVA of mean dwell time with the factor of cue type (predictive vs. irrelevant) revealed a non-significant main effect, $F_{(1,15)} = 2.86$, $\eta_p^2 = .16$, $p = .112$, 95% CI [NA, .40]. Figure 4.18b reveals that predictive reinforced cues attracted the most dwell time, followed by predictive non-reinforced cues, then irrelevant cues presented on non-reinforced trials, and finally, irrelevant cues presented on reinforced trials. A two-way repeated measures ANOVA of mean dwell time with the factors of cue type (predictive vs. irrelevant) and reinforcement (reinforced vs. non-reinforced) revealed a non-significant main effect of predictiveness, $F_{(1,15)} = .96$, $\eta_p^2 = .06$, $p = .343$, 95% CI [NA, .29],

reinforcement, $F_{(1,15)}$ = 2.86, η_p^2 = .16, p = .112, 95% CI [NA, .40], and a non-significant interaction, $F_{(1,15)}$ = .68, η_p^2 = .04, p = .422, 95% CI [NA, .26].

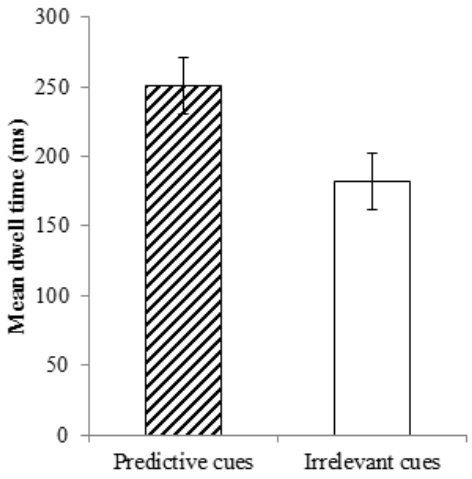


Figure 4.18a *Mean dwell time directed towards predictive and irrelevant cues*

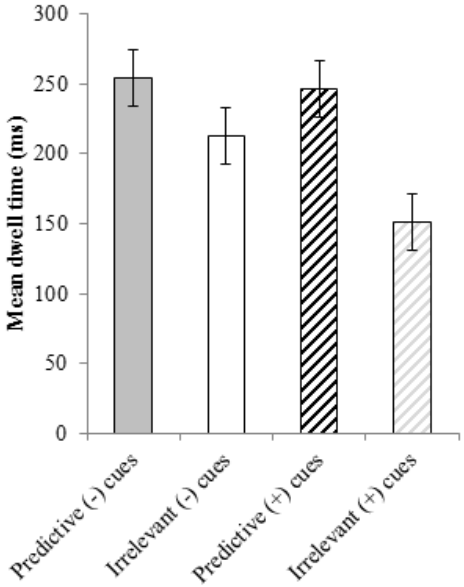


Figure 4.18b *Mean dwell time directed towards predictive reinforced, predictive non-reinforced, irrelevant reinforced and irrelevant non-reinforced cues*

Cue presentation terminated when participants made a response and consequently RT decreased over training, therefore, eye gaze was calculated as a proportion of trial duration by dividing dwell times for each stimulus type by the RT for each trial. Figure 4.19a reveals that predictive cues attracted a higher proportion of dwell time compared to irrelevant cues. A one-way repeated measures ANOVA of mean proportion of dwell time with the factor of cue type (predictive vs. irrelevant) revealed a significant main effect, $F_{(1,15)}$ = 10.99, η_p^2 = .42, p = .005, 95% CI [.10, .61]. Figure 4.19b reveals that predictive reinforced cues attracted the largest proportion of dwell time, followed by irrelevant cues presented on non-reinforced trials, then predictive reinforced cues, and finally,

irrelevant cues presented on reinforced trials. A two-way repeated measures ANOVA of mean proportion of dwell time with the factors of cue type (predictive vs. irrelevant) and reinforcement (reinforced vs. non-reinforced) revealed a significant main effect of reinforcement, $F_{(1,15)} = 11.00$, $\eta_p^2 = .42$, $p = .005$, 95% CI [.18, .51], a non-significant main effect of predictiveness, $F_{(1,15)} = .54$, $\eta_p^2 = .04$, $p = .474$, 95% CI [NA, .25], and a significant interaction, $F_{(1,15)} = 6.66$, $\eta_p^2 = .31$, $p = .021$, 95% CI [.03, .53]. Simple main effects analysis of this interaction revealed a significant main effect of predictiveness on reinforced trials only, $F_{(1,15)} = 6.68$, $\eta_p^2 = .31$, $p = .021$, 95% CI [.03, .53]. It's worth noting that non-reinforced trials were almost twice the length of reinforced trials (2327 & 1855 ms respectively).

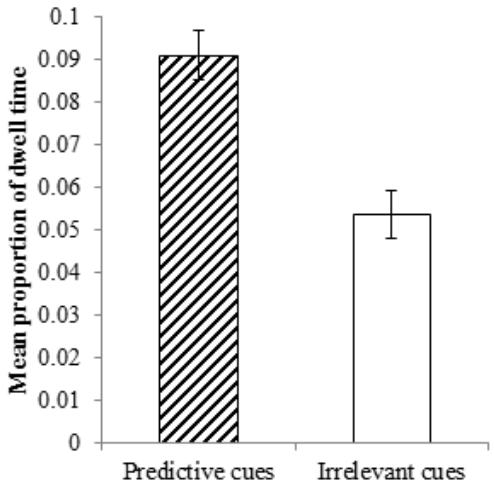


Figure 4.19a *Mean proportion of dwell time directed towards predictive and irrelevant cues*

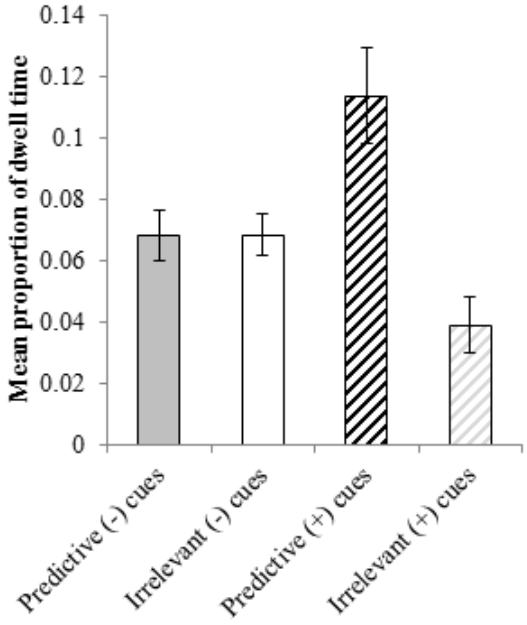


Figure 4.19b *Mean proportion of dwell time directed towards predictive reinforced, predictive non-reinforced, irrelevant reinforced and irrelevant non-reinforced cues*

4.3.2.1 *Questionnaire data*

Participants were given a questionnaire which tested their understanding of the associative relationship between predictive and irrelevant cues with the occurrence and omission of the grape. Participants answered questions on a ten-point scale, with '10' being 'causes grape' and '1' being 'prevents grape'. A one-way repeated measures ANOVA of questionnaire scores with the factor of cue type (reinforced, non-reinforced & irrelevant) revealed a significant main effect of cue type, $F_{(1.35,25.61)} = 34.84$, $\eta_p^2 = .65$, $p < .001$, 95% CI [.27, .68]. Bonferroni corrected t-tests also revealed a significant difference between predictive reinforced cues and irrelevant cues, $t_{(38)} = 6.55$, $p < .001$, but a non-significant difference between predictive non-reinforced cues and irrelevant cues, $t_{(38)} = .778$, $p = .442$.

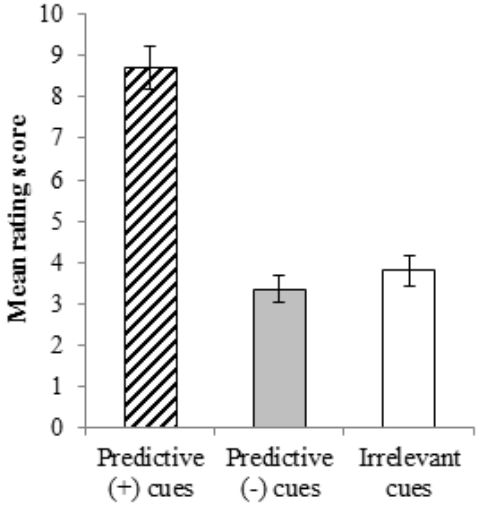


Figure 4.20 *Mean rating score given for predictive reinforced, predictive non-reinforced and irrelevant cues*

4.3.3 **Discussion**

Overall, Experiment 8 failed to demonstrate that adult participants would come to acquire an overt bias in visual attention towards cues that were predictive of an outcome. This result is in stark contrast to the results of Experiments 7 and 8, conducted with an orangutan and children respectively, which, using comparable procedures, revealed reliable "learned predictiveness" effects. A further analysis of the data, however, revealed the source of this difference – adults only acquired a learned bias in dwell time towards a cue that was paired with reward. On trials in which reward was omitted, there was no difference in selective attention. To avoid undue repetition, we will consider the theoretical implications of this result in the general discussion to this chapter.

One possible explanation for this is that it is possible for participants to achieve high accuracy without learning both contingencies. For example, participants could have only learned that they would be rewarded when they saw cue A, and responded solely on this basis, and did not learn the significance of any other stimuli. When analysing the mean rating scores given by participants in the questionnaire at the end of the experiment, the data revealed a significant difference between predictive reinforced cues and irrelevant cues, but no difference between predictive non-reinforcement cues and irrelevant cues. This suggests that participants only learned the predictive contingency for reinforced trials.

4.4 General discussion

Existing research into how humans and animals allocate selective attention during associative learning tasks have employed dissimilar experimental methodologies which use different measures to quantify attention. Previous studies using human subjects have tended to provide support for the Mackintosh (1975) model (e.g. Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al., 2012), whilst studies using animal subjects have more often provided support for the Pearce-Hall (1980) model (e.g. Dickinson, Hall & Mackintosh, 1976; Haselgrove, Esber, Pearce & Jones, 2010; Kaye & Pearce, 1984; Swan & Pearce, 1988; Wilson, Boumphrey & Pearce, 1992). This divergence in behavioural performance has been suggested to reflect a difference in the underlying associative mechanism used to direct selective attention towards good predictors or uncertain predictors of an outcome. However, it is difficult to compare the results of human and animal experiments as they frequently use different experimental designs.

Chapter 4 established a simplified version of the learned predictiveness task to back-translate eye-tracking methodology, often used when testing adult humans, into an orangutan and into human children to determine whether the dichotomy between human and animal findings reflects a difference in the underlying mechanisms used to direct attention, or is a by-product of the testing procedure. Experiment 6 revealed that the learned predictiveness effect is not an ability constrained to humans since the orangutan also directed more fixations towards predictive cues than irrelevant cues. This is important because it

suggests that the contrast between the performance of humans and animals results from a difference in the methodology used to test them and implies that if tested under the same conditions their performance would be comparable.

As children age they become more proficient at disengaging their visual attention and shifting it towards relevant information within their environment, reflecting changes in their high-level cortical systems (Zanto, Rubens, Thangavel & Gazzaley, 2011). Experiment 7 revealed that children who learned the task demonstrated the learned predictiveness effect, however, no effect of age was observed. An explanation for this finding could be that changes in attentional allocation occur earlier in development, before infants are 1-year-old (Atkinson & Braddrick, 2012).

Experiment 8 employed the same experimental paradigm and used a similar methodology when testing adult human participants that were used to test the orangutan in Experiment 6 and children in Experiment 7 because many comparative studies between humans and animals use very different setups which makes comparisons difficult. Unfortunately, it was not possible to correlate eye gaze distribution over the three participant types because there was a large variation in the number of fixations captured when testing the orangutan since she could not be instructed to attend to the screen.

Chapter 4 also addressed whether the learned predictiveness effect was present on non-reinforced trials as well as reinforced trials. Previous research using a learned predictiveness task (e.g. Le Pelley & McLaren, 2003; Le Pelley et al., 2011; Beesley et al., 2015) used predictive contingencies where participants were required to predict which of multiple outcomes would occur. However, in the real-world cues are not always followed by the presence of an outcome, they

are sometimes followed by the omission, and it is equally important for individuals to be able to learn about these relationships. An example using the allergist paradigm could be that consuming Food 1 results in a headache, but consuming Food 2 is followed by nothing and therefore is safe to eat.

Experiments 6 and 7 found that predictive cues on reinforced and non-reinforced trials received more attention than irrelevant cues in the orangutan and children. This reveals that the learned predictiveness effect can be demonstrated on reinforced and non-reinforced trials. However, Experiment 8 only found a bias towards predictive cues on reinforced trials, suggesting that a cue's associability is influenced by whether it is reinforced or non-reinforced. Moreover, Pearce, Dopson, Haselgrove and Esber (2012) found that not all types of irrelevant cues acquire the same amount of associability. In a series of experiments on rats and pigeons they revealed that irrelevant cues (X) in a blocking procedure (A+ AX+) acquired more associability than irrelevant cues (Y) that had been partially reinforced in a simple discrimination (BY+ CY-). Although, further investigation in Experiment 8 using questionnaire data revealed that adults only learned the predictive contingency on reinforced trials.

This difference in performance observed between adults and children or animals could result from the use of different conditioning mechanisms. It could be that visual attention in adults is more under the control of instrumental conditioning mechanisms, like that proposed by Spence (1936). Spence suggested that differential responding to S+ and S- reflects both conditioned excitation to S+ and conditioned inhibition to S-, and according to the current experiment this would mean that participants should have looked more towards cues that predicted reinforcement and less towards cues that predicted non-

reinforcement. However, it has been observed in previous research by Anderson, Laurent and Yantis (2011) that adult learned visual attention can be quite counterproductive. Anderson et al. found that participants looked at a distractor that was the same colour (now task irrelevant) that had previously been paired with a high value reward in the training stage, even when it was detrimental to successfully completing the task. Both the Le Pelley (2004) and Esber-Haselgrove (2011) models can explain these findings because they have separate learning algorithms for excitatory and inhibitory learning, and therefore have the necessary components to simulate differences in the contribution of reward-based and non-reward-based learning on associative strength (and ultimately learning). For example, both models have learning rate parameters associated with the presence and absence of reward (β) perhaps these learning rate parameters are relatively similar for animals (orangutans) and children, but for adults, the β for nonreinforced trials is relatively low. However, it remains to be determined whether it is indeed accurate, and if so, why such a difference might emerge. One possibility is that having a bias in learning rate permits associative learning to be strategic and efficient. By only learning half of the categorisation task, that is to say by only acquiring half of the mappings between stimulus and outcome (Experiment 8) permits the expression of discriminative control, but in a manner that is rather like, "Cue A signals food, everything else doesn't." If this strategy is multiplied up to complex tasks (like in Experiment 1) then it permits quite a saving in learning.

4.5 Conclusion

Previously the learned predictiveness effect had only been demonstrated in adult human participants, but Experiments 6 and 7 found that an orangutan and children also directed more attention towards predictive cues than irrelevant cues. This suggests that the difference in performance of animals and humans shown in the literature does not arise from a difference in the underlying mechanism used to direct selective attention during associative learning, but instead arises from a difference in the methodology used to test them. Experiments 6 and 7 also found that cues which were predictive of the absence of reinforcement enjoyed the same enhanced attention as those which were predictive of reinforcement. This suggests that the Mackintosh (1975) and Le Pelley (2004) models can be used to interpret findings on both reinforced and non-reinforced trials. However, in Experiment 8 adult humans only directed increased attention towards predictive cues on reinforced trials because they did not learn the other predictive contingency.

Chapter 5:

The relevance of prediction in learned predictiveness

Learned predictiveness tasks have reliably shown that good predictors of an outcome attract more overt visual attention, and enter into new associations more readily, compared to poor predictors (see: Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al., 2012). This has become known as the predictiveness principle: "*the predictiveness principle refers to the idea that cues become more psychologically salient as a result of their predictiveness with respect to important outcomes; more attention will be allocated to predictive cues than to nonpredictive cues,"* (Le Pelley et al., 2016, p. 8).

These results are often interpreted as providing support for Mackintosh's (1975) model of associative learning, which predicts that a cue's associability will increase if it is the best available predictor of reinforcement – highlighting the importance of predictive validity. However, simultaneous conditioning studies have found that associative learning persists even in the absence of a temporal, predictive relationship between stimuli (see: Burkhart & Ayres, 1978; Heth & Rescorla, 1973; Mowrer & Aiken, 1954; Rescorla, 1980). For example, the experiment by Rescorla employed a novel stimulus sequence in order to compare simultaneous with sequential associations amongst neutral stimuli in a sensory preconditioning procedure. From these results, it is clear that stimuli can be correlated and associated with each other without being predictive. In fact, using a favour-aversion paradigm in rats, Rescorla (1980) found that simultaneous associations were stronger than sequential associations.

Contiguity refers to the temporal relationship between a cue and an outcome. It is assumed that the smaller the temporal difference, the easier two

events will enter into association with each other. Earlier studies (see Thompson, 1972, for a review) found that forward conditioning was better than simultaneous conditioning, but Rescorla (1980) revealed that this was due to generalisation decrement. Therefore, perfect contiguity appears to be optimal for association formation and based on this assumption it shouldn't be surprising that Rescorla (1980) found stronger associations using simultaneous conditioning because cues presented at the same time have the smallest possible temporal distance.

On the other hand, more recently the importance of predictive validity has been emphasised in learned attention (e.g. Le Pelley et al., 2011; Beesley et al., 2015). Despite this, the models of associative learning used to explain these findings the formalisation of these models do not incorporate separate functions for associative strength and prediction to allow them to influence attention independently. Although, it is possible to form associations without prediction, and as Rescorla (1980) showed sometimes these can be better. Consequently, it remained unknown what the role of association was when no prediction was made, and whether prediction was necessary for learned variations in attention to be established. Therefore, Chapter 4 explored whether learned variations in attention operated under circumstances of association, but in the absence of prediction.

5.1 Experiment 9

The aim of Experiment 9 was to establish a scenario in which a stimulus and a target were correlated with each in the absence of a predictive relationship between them, to determine whether under these circumstances, dwell time would increase towards stimuli that were correlated with a target than uncorrelated stimuli. To achieve this, participants were simultaneously presented with triplets of stimuli, comprising a target stimulus (that participants were required to respond to), a correlated stimulus (that was always presented with the target stimulus) and an uncorrelated stimulus (presented with the target stimulus on 50% of trials). Eye gaze towards correlated and uncorrelated stimuli was analysed to determine whether participants had acquired an attentional bias towards correlated stimuli on the basis of their co-occurrence with the target stimulus. According to associative analyses of attention (e.g. Esber-Haselgrove, 2001; Le Pelley, 2004; Mackintosh, 1975), a stimulus that is correlated with the occurrence of the target will acquire more attention than a stimulus that is uncorrelated with the occurrence of the target. The same prediction does not necessarily hold if it is thought that prediction is an important determinant of learned changes in attention (e.g. Le Pelley, 2016).

5.1.1 **Methods**

5.1.1.1 ***Participants***

Eighteen undergraduate students from The University of Nottingham participated in return for course credit or £3. The sample consisted of 14 females

(Mean ± SD: 19.57 ± .94). Exclusion criteria were the same as in previous experiments.

5.1.1.2 *Apparatus and stimuli*

The experiment was designed and run using Experiment Builder. A SR Research Eyelink 1000 Plus eye-tracker sampled participant's right eye at a rate of 1000 Hz. Thresholds used to define fixations and saccades were: .15° displacement, 30°/s velocity and 8,000°/s^2 acceleration. Participants viewed stimuli binocularly from a distance of 67 cm; and head movements were minimised using a chin and forehead rest. Stimuli consisted of the letters U, V, W, X, Y and Z, in black, size 60, Times New Roman font. The screen was a BenQ XL2420T LED monitor (33 × 57 cm) with resolution set to 1920 × 1080 at 114 Hz. Cues were presented 5 cm apart from each other, forming an equilateral triangle (see Figure 5.1), the centre of which coincided with the centre of the screen. All stimuli were presented on a white background and subtended a visual angle of 25.36°. ROI were set to 2.7 × 2.7 cm squares around each letter.

Stimuli were assigned to serve as either the target, correlated or uncorrelated stimuli (see Table 5.1). There were 288 trials overall, divided into 16 trial blocks of 18 trials. In order to measure dwell time to the correlated and uncorrelated stimuli in the absence of the target (which may reasonably be expected to command most of the visual attention during the trial) there were 24 trials with the correlated and uncorrelated stimuli randomly presented but the target omitted. Trial order was randomised over the whole experiment (312 trials in total). All versions were fully counterbalanced (see Appendix 7), and stimulus

position was varied during the experiment to ensure that target, correlated and uncorrelated stimuli were presented equally frequently in all three positions.

Table 5.1 *Experimental design for Experiment 9*

Stimuli	*Correct response*	*Probe trials*
U+W+Y	**Y**	**U+W**
U+X+Y	**Y**	**U+X**
V+X+Z	**Z**	**V+X**
V+W+Z	**Z**	**V+W**

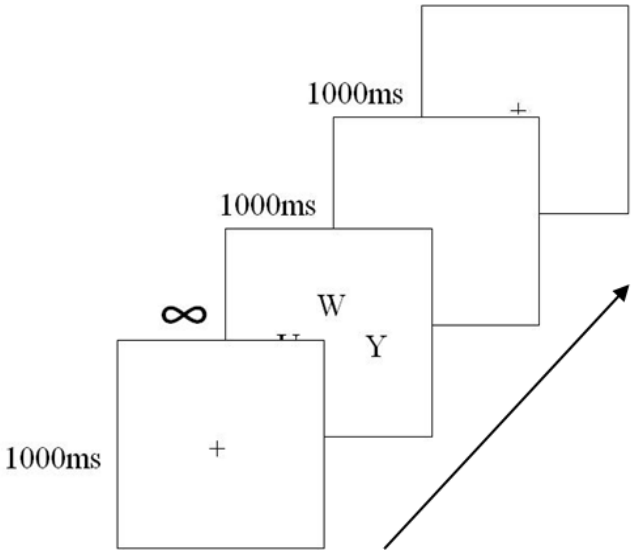


Figure 5.1 *Temporal layout of a trial during Experiment 9*

5.1.1.3 ***Procedure***

Eye movement data were recorded from participant's right eye. The eye-tracker was calibrated for each participant at the outset of the experimental session using a nine-point calibration, except for two participants who could

only be calibrated using a five-point procedure. A brief health questionnaire was administered to screen for exclusion criteria, written instructions were given, and informed consent was gained.

At the start of each experimental session, the experimenter checked that both pupil and corneal reflections were present whilst participants read the on-screen instructions before performing a calibration. Written instructions: "*Thank you for participating in this study. Your first task is to focus on the dot and follow it with your eyes. Press the space bar to begin the experiment.*" After performing the calibration participants read further on-screen instructions: *"Each trial will begin with a fixation cross in the centre of the screen. You need to look directly at the cross. Following this, your task is to indicate whether the letter Y or Z is present in the array. Try to remember which letters are paired together because at the end of the experiment you will have a memory test. Y = left, Z = right. Press any key to start the experiment."*

Participants were then presented with three letters (Figure 5.2) on the screen and were required to indicate the identity of the target stimulus as fast as they could, using the left and the right arrows which had stickers with the target letters on. On the target-missing trials no response was required.

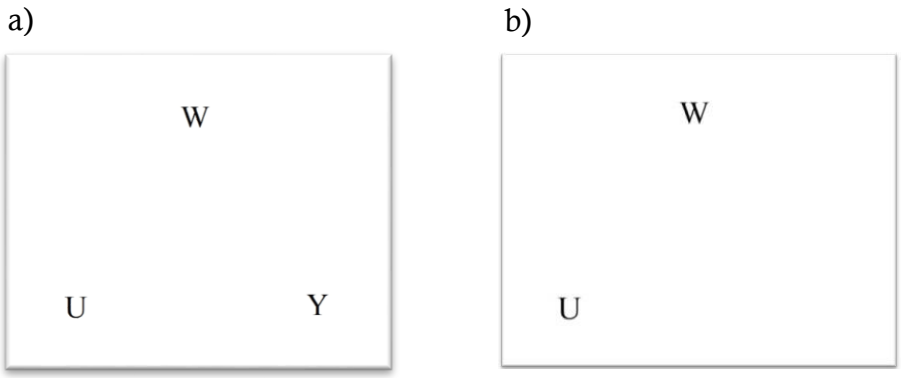


Figure 5.2 *Spatial layout of **a)** a trial with all three stimuli present **b)** a trial with the target stimulus omitted*

After participants completed the experiment they were given a brief questionnaire which tested their understanding of the relationship between the two correlated and two uncorrelated stimuli with target stimuli by asking participants to rate the likelihood of the stimuli pairing (see Figure 5.3). Upon completion participants were thanked for their time and debriefed.

How likely was the letter 'Y' to be paired with the following letters?
(please circle)

	Unlikely									Likely
Letter 'U'	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Letter 'V'	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Letter 'W'	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Letter 'X'	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**

Figure 5.3 *Sample questions from the questionnaire*

5.1.2 **Results**

Occasionally the eye-tracker lost track of pupil and corneal reflections, resulting in missing eye movement data. To overcome this problem, the same exclusion criteria used in Experiment 1 were imposed; participants were excluded from further analysis if the percentage of missing data were greater than 20% (zero participants were excluded on this basis), or if they achieved less than 60% correct responses across all trial blocks (zero participants were excluded on this basis).

5.1.2.1 ***Behavioural data***

Figure 5.4a shows the mean proportion of correct responses over trial blocks and reveals that participants performed the task with high accuracy from trial block 1, and therefore improved only slightly over the course of the experiment. Trial block 16 had an average accuracy of almost 96%, which a one-sample t-test reported as significantly above chance (.5), $t_{(17)} = 69.28$, $p < .001$. A one-way repeated measures ANOVA of mean proportion accuracy with the factor of block (1-16) revealed a non-significant main effect, $F_{(5.12,86.96)} = .73$, $\eta_p^2 = .04$, $p = .605$, 95% CI [NA, .07], reflecting the lack of change over training. In addition, Figure 5.4b reveals that RT remained relatively constant throughout the experiment. Consequently, a one-way repeated measures ANOVA of RT with the factor of block (1-16) also revealed a non-significant main effect, $F_{(3.55,60.35)} = .66$, $\eta_p^2 = .04$, $p = .606$, 95% CI [NA, .09].

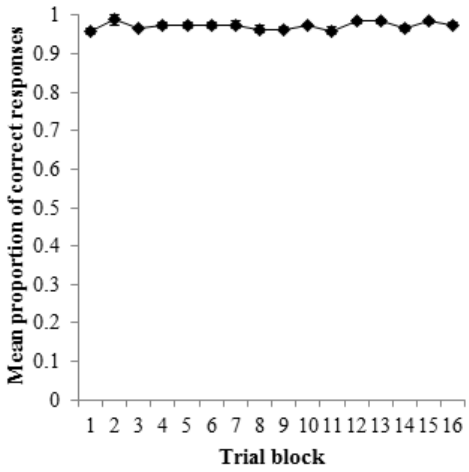


Figure 5.4a *Mean proportion of correct responses across trial blocks*

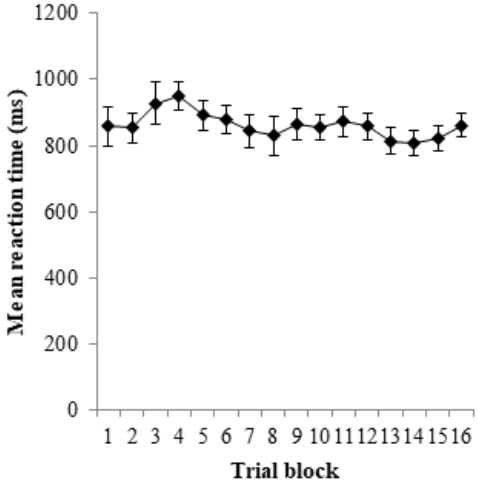


Figure 5.4b *Mean RT across trial blocks*

5.1.2.2 *Eye gaze analysis*

The mean proportion of dwell time that participants directed towards the correlated, uncorrelated and target stimuli over 16 blocks are shown in Figure 5.5. This reveals that target stimuli attracted the largest proportion of dwell time, and very little was directed either towards correlated and uncorrelated stimuli. A two-way repeated measures ANOVA of proportion of dwell time with the factors of stimulus type (target vs. correlated vs. uncorrelated) and trial block (1-16) revealed a significant main effect of stimulus type, $F_{(1.13,19.12)} = 58.02$, $\eta_p^2 = .77$, $p < .001$, 95% CI [.57, .84], trial block, $F_{(4.28,72.81)} = 4.43$, $\eta_p^2 = .21$, $p = .002$, 95% CI [.05, .30], and a significant interaction, $F_{(22,374)} = 1.86$, $\eta_p^2 = .10$, $p = .050$, 95% CI [.01, .10]. Simple main effects analysis of this interaction revealed a significant difference between the proportion of dwell time directed towards target stimuli and correlated or uncorrelated stimuli from block 1 onwards, smallest, $F_{(1.13,19.12)} = 26.03$, $\eta_p^2 = .51$, $p < .001$, 95% CI [NA, .26], with target stimuli always attracting a higher proportion of dwell time.

It was important to ascertain whether this non-significant difference between correlated and uncorrelated stimuli supported the null hypothesis (there was no difference between the proportion of dwell time directed towards correlated and uncorrelated stimuli), or supported no conclusion at all (Dienes, 2011). To decide between these two possibilities, a Bayes factor analysis was conducted. A Bayes factor of less than .33 would support the null hypothesis, above 3 would provide support for the alternative hypothesis, and in between the two values provides inconclusive evidence for either the null or the alternative hypothesis. In order to calculate the Bayes factor, a plausible effect size needed to be provided. To do this, the mean difference in proportion of dwell time directed towards the predictive and irrelevant stimuli in Experiment 1 was used, which was .1 for all participants. For the current experiment, we observed a mean difference of -.001 between the proportion of dwell time directed towards correlated and uncorrelated stimuli for all participants. Following Dienes (2011: see: http://www.lifesci.sussex.ac.uk/home/Zoltan_Dienes/inference /Bayes.htm), the data were modelled using a two-tailed distribution with a mean of 0 (indicating no difference between the proportion of dwell time directed towards correlated and uncorrelated stimuli) and standard error (SE) was set to .005. This yielded a Bayes factor of .05, which allowed us to accept the null hypothesis, there was no difference between the proportion of dwell time directed towards correlated and uncorrelated stimuli.

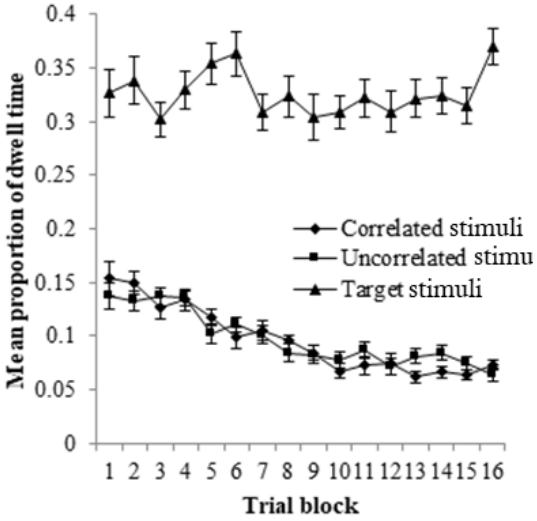


Figure 5.5 *Mean proportion of dwell time directed toward correlated, uncorrelated and target cues across trial blocks*

One possible explanation for the absence of a difference between the proportion of dwell time directed towards correlated and uncorrelated stimuli is that participants were directing so much attention towards the, task relevant, target stimulus, that attention towards the remaining stimuli on the screen was at floor levels. To examine this possibility, 24 trials where the target stimulus was absent were incorporated into the experimental design, with the aim of increasing the amount of overt visual attention that correlated and uncorrelated stimuli attracted. Figure 5.6 reveals that on the 24 target-absent trials, the mean proportion of dwell time directed towards correlated and uncorrelated stimuli was longer than it was during the trials that included the target, but there was still no difference between these stimuli. A two-way repeated measures ANOVA of proportion of dwell time with the factors of stimulus type (correlated vs. uncorrelated) and trial number (1-24) revealed a non-significant main effect of stimulus type, $F_{(1,17)} = .04$, $\eta_p^2 = .002$, $p = .850$, 95% CI [NA, .11], trial number,

$F_{(6.60,112.19)}$ = 1.76, η_p^2 = .09, p = .107, 95% CI [NA, .14], and a non-significant interaction, $F_{(7.81,132.79)}$ = .73, η_p^2 = .04, p = .659, 95% CI [NA, .05]. A Bayes factor was again calculated for the difference between correlated and uncorrelated stimuli using an observed mean difference of .0001 ms, and a SE set to .005. This yielded a Bayes factor of .05, which allowed us to again accept the null hypothesis, there was no difference between the proportion of dwell time directed towards correlated and uncorrelated stimuli.

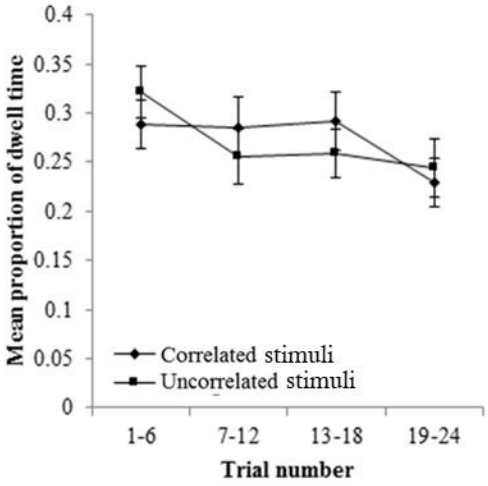


Figure 5.6 *Mean proportion of dwell time directed towards correlated and uncorrelated cues on trials where the target was omitted*

5.1.2.3 ***Questionnaire data***

Participants were given a questionnaire which tested their understanding of the associative relationship between correlated and uncorrelated stimuli with target stimuli. A difference score was calculated to determine the specificity of the stimulus-target relationship. For the correlated stimulus, this was computed

by subtracting the rating of the relationship between the correlated stimulus and the target stimulus it was not paired with from the rating of the relationship between the same correlated stimulus and the target stimulus that it was paired with (e.g. the rating of the relationship between U and Z was subtracted from the rating of the relationship between U and Y). For the uncorrelated stimulus, this was computed by subtracting the rating of the relationship between the uncorrelated stimulus and a target stimulus from the rating of the relationship between the same uncorrelated stimulus and the other target stimulus that it was paired with (e.g. the rating of the relationship between W and Y was subtracted from the rating of the relationship between W and Z) (UY-UZ, VY-VZ, WY-WZ, XY-XZ). Figure 5.7 reveals that the difference score was higher for correlated stimuli compared to uncorrelated stimuli, ($t_{(34)} = 6.69$, $p < .001$). The mean difference rating for correlated stimuli was significantly above zero, ($t_{(17)} = 4.37$, $p < .001$), but not for uncorrelated stimuli, ($t_{(17)} = 1.46$, $p = .161$).

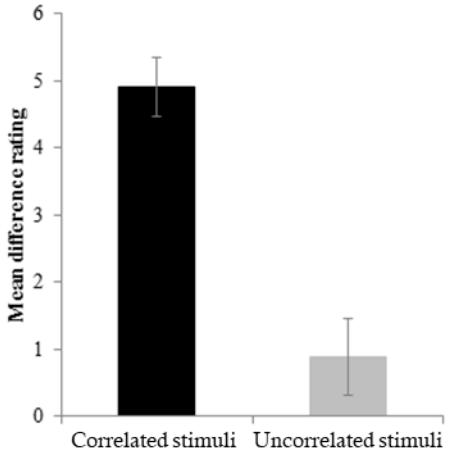


Figure 5.7 *Mean absolute difference rating given for correlated and uncorrelated cues*

5.1.3 **Discussion**

In the current experiment participants were required to indicate the identity of a target stimulus on each trial by pressing the corresponding button. The aim of Experiment 9 was to determine whether attention would bias towards the stimulus that was better correlated with a target under circumstances where there was no *predictive* relationship between them. Our findings revealed no difference in dwell time towards the correlated relative to the uncorrelated stimuli. This finding could have resulted from low levels of overt attention being directed towards non-target stimuli. However, the probe trials in which the target was absent render this explanation unlikely because the same pattern of results was observed irrespective of whether the target was present or absent. Alternatively, subjects might have failed to attend to the correlated stimulus because it was not associated with the target stimulus. However, questionnaire results revealed that participants were aware of the associative relationships between correlated and uncorrelated stimuli and target stimuli

This finding stands at odds with the attentional model of associative learning proposed by Mackintosh (1975), which is commonly used to explain the learned predictiveness effect by referring to changes in attention. This is because this model suggests that attention increases to a stimulus if its error term is smaller than the error term for any other stimuli on that trial. However, the questionnaire in Experiment 9 revealed that the participants target specific associative knowledge of the correlated stimuli was significantly higher than that of the uncorrelated stimuli, implying that the error term for the correlated stimuli was higher than the uncorrelated stimuli, and hence the former stimuli should

have an enjoyed a relative increase in attention, an attentional bias failed to develop towards correlated stimuli and away from uncorrelated stimuli. Other models of associative learning are similarly troubled (e.g. Esber & Haselgrove, 2011; Kruschke, 2001; Le Pelley, 2004; Pearce & Mackintosh, 2010) because they also claim that attentional changes occur automatically on the basis of the strength of the association between a cue and an outcome.

However, Le Pelley (2004) claimed that α could be 'sticky' if it was too high or too low, that is to say not amenable to change; perhaps then the stimuli employed in the current experiment were especially 'sticky'. On the other hand, an attentional bias may not have developed because Experiment 9 utilised a novel paradigm, involving target detection and stimuli that might not support learned variations in attention. To address this issue, a positive control is required in which the same stimuli are employed in a procedure that does result in learned changes in dwell time. This was the purpose of Experiment 10.

5.2 Experiment 10

Experiment 9 found no bias in learned attention towards cues that were correlated with the identity of target stimuli; however, it currently remains unclear whether the stimuli employed in Experiment 9 were able to support learned variations in attention. Building on this, the aim of Experiment 10 was to investigate whether overt attention would bias towards correlated or uncorrelated stimuli when presented serially with target stimuli, that is to say when a predictive relationship is established between the correlated cues and the target stimulus, a relationship more regularly encountered in standard learned predictiveness tasks (e.g. Le Pelley & McLaren, 2003; Le Pelley et al., 2011). Moreover, we were keen to investigate whether the presence of a predictive relationship between correlated stimuli and target stimuli was sufficient to allow a learned attentional bias to develop (Group Target) or, if in addition to this, participants needed to make an overt prediction about the presence of the target prior to its appearance (Group Cue). During the experiment, stimulus compounds containing a correlated stimulus (which always preceded a specific target stimulus) and an uncorrelated stimulus (preceding each target stimulus on 50% of trials) were paired serially with a target stimulus. In Group Target, participants were instructed to only respond once the target appeared; however, Group Cue, could also respond early – make a prediction – when the correlated and uncorrelated stimuli were on-screen. A final group, Group simultaneous, replicated the group employed in Experiment 9. Again, at the end of the experiment, all groups received a questionnaire to determine their knowledge of the relationship between the correlated, uncorrelated and target stimuli

On the basis of the results of Experiment 9, we expect to see no difference in dwell times towards the correlated and uncorrelated stimuli in Group Simultaneous. What remains to be determined is whether the two serial groups, Group Target and Group cue, would show evidence of differences in attention to the correlated and uncorrelated stimuli when a predictive relationship was established between these stimuli and the target; and perhaps most interestingly whether these two groups would differ themselves.

5.2.1 **Methods**

5.2.1.1 ***Participants***

Each group contained 18 undergraduate students from The University of Nottingham who participated in return for course credit. In Group Simultaneous, the sample consisted of 18 females with a mean age of 18.5 ± .86 (Mean ±SD). In Group Target, the sample consisted of 18 females with a mean age of 18.33 ± .49. In Group Cue, the sample consisted of 17 females with a mean age of 19 ± 1.27. Exclusion criteria for all groups were the same as in previous experiments.

5.2.1.2 ***Apparatus and stimuli***

All versions of the experiment were programmed using Experiment Builder and conducted on an EyeLink 1000 Plus eye-tracker. Stimuli consisted of the letters J, P, Q, V, W and Z, which all have a similar frequency in the English language. Letters were presented in black (-1, -1, -1), size 60, Times New

Roman font. Letters Q and P always served as the target stimuli, whilst letters J, V, W and Z were randomly assigned to serve as either the correlated (J & V) or uncorrelated stimuli (W & Z) (see Table 5.2 and Appendix 8 for full counterbalancing). The screen was a BenQ XL2420T LED monitor (33 × 57 cm) with resolution set to 1920 × 1080 at 114 Hz. All stimuli were presented on a white (1,1,1) background, subtended a visual angle of 25.36°, and ROI were set to 2.7 × 2.7 cm squares around them.

Each correlated and uncorrelated stimulus was presented 72 times making 144 trials overall, divided into 8 trial blocks of 18 trials. Correlated and uncorrelated stimuli were presented 5 cm apart from each other on all trials, and appeared randomly at different corners of an equilateral triangle. In Group Simultaneous the target appeared with the correlated and uncorrelated stimuli, but in Group Target and Cue, the target appeared alone in a randomised location on the subsequent screen. Eight probe trials were also included, in which a correlated and uncorrelated stimulus were presented in the absence of a target stimulus, and participants predicted what they thought the target stimulus would have been.

Table 5.2 *Experimental design of Experiment 10*

Condition	*Stimuli*	*Correct response*	*Probes*
Simultaneous	**JWQ**	**Q**	**JW**
	VZP	**P**	**VZ**
	JZQ	**Q**	**JZ**
	VWP	**P**	**VW**
Target & Cue	**JW→Q**	**Q**	**JW**
	VZ→P	**P**	**VZ**
	JZ→Q	**Q**	**JZ**
	VW→P	**P**	**VW**

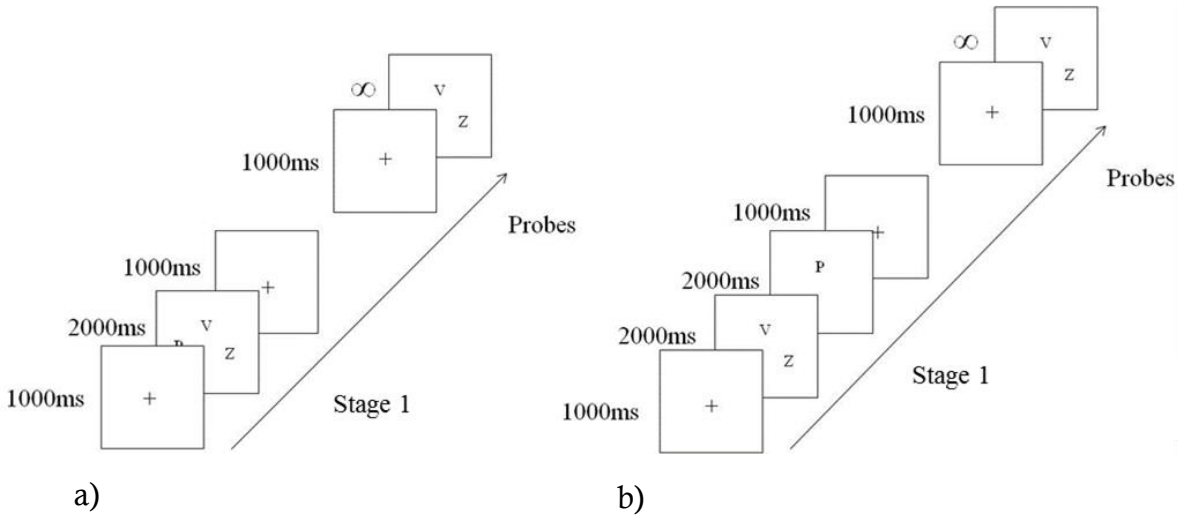


Figure 5.8 *Temporal layout of **a)** Group Simultaneous **b)** Group Target or Group Cue*

5.2.1.3 *Procedure*

Eye movement data were recorded from participant's right eye. The eye-tracker was calibrated for each participant at the outset of the experimental session using a nine-point calibration. A brief health questionnaire was administered to screen for exclusion criteria. At the start of each experimental session, the experimenter checked that pupil and corneal reflections were

present. Following this, on-screen instructions appeared: "*Thank you for participating in this study. Your first task is to focus on the dot and follow it with your eyes. Press the space bar to begin the experiment.*" After performing the calibration, participants read further on-screen instructions. "*Each trial will begin with a fixation cross in the centre of the screen. This will be followed by a series of letters. Your task is to indicate whether the letter 'Q' or 'P' is present in the array. Q = left arrow, P = right arrow. Pay attention to which stimuli are paired together because at the end you will have a memory test. Press any key to start the experiment.*" In Group Cue, participants were additionally told, "*You can press early if you think you know which letter will appear.*"

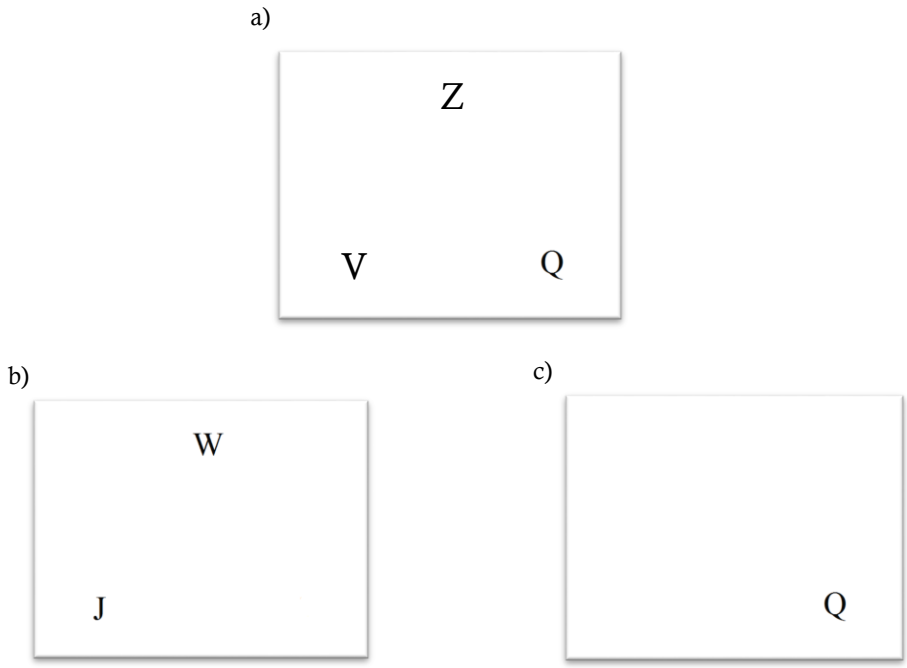


Figure 5.9 *Spatial layout of **a)** all three stimuli in Group Simultaneous, **b)** correlated and uncorrelated stimuli in Group Target or Group Cue, **c)** the target stimulus in Group Target or Group Cue*

After participants completed the experiment they were given a brief questionnaire to complete which tested their understanding of the relationship between correlated and uncorrelated stimuli with target stimuli. The questionnaire was the same as that used in Experiment 9.

5.2.2 **Results**

Exclusion criteria were set to less than 60% correct responses across all trial blocks (zero participants were excluded on this basis), and greater than 20% missing eye-tracking data (zero participants were excluded on this basis). For subsequent analysis Greenhouse-Geisser corrections were applied where sphericity was violated.

5.2.2.1 ***Behavioural data***

Figure 5.10a reveals that participants responded with high accuracy in all groups from block 1 onwards, and therefore only improved slightly over the course of the experiment. In Groups Simultaneous, Target and Cue the mean proportions of correct responses in trial block 8 were 98%, 95% and 89% respectively. One sample t-tests revealed that each of these means was significantly greater than chance (.5), smallest $t_{(17)} = 773.98$, $p < .001$. A two-way mixed measures ANOVA of mean proportion correct responses with the within factor of trial block (1-8) and between factor of group (Group Simultaneous vs. Group Cue vs. Group Target), revealed a non-significant main effect of group, $F_{(1,30)} = 2.01$, $\eta_p^2 = .12$, $p = .151$, 95% CI [NA, .23], trial block, $F_{(17,105)} = .88$, $\eta_p^2 =$

.06, p = .529, 95% CI [NA, .09], and a non-significant interaction, $F_{(14,210)}$ = 1.03, η_p^2 = .06, p = .421, 95% CI [NA, .06].

Figure 5.10b shows the mean RT across trial blocks for all groups, with the dotted grey line indicating the time of the onset of the target stimulus. In all groups RT remained relatively constant throughout the experiment, although at different levels. For Group Cue, RT was below 2000 ms from block 1 onwards because participants were responding before the onset of the target stimulus. A two-way mixed measures ANOVA of mean RT with the within factor of trial block (1-8) and the between factor of group (Group Simultaneous vs. Group Cue vs. Group target), revealed a significant main effect of group, $F_{(1.61, 20.85)}$ = 473.94, η_p^2 = .97, p < .001, 95% CI [.95, .98], trial block, $F_{(3.52,45.69)}$ = 16.50, η_p^2 = .56, p < .001, 95% CI [.36, .64], and a non-significant interaction, $F_{(3.37,43.77)}$ = 1.04, η_p^2 = .07, p = .417, 95% CI [NA, .16].

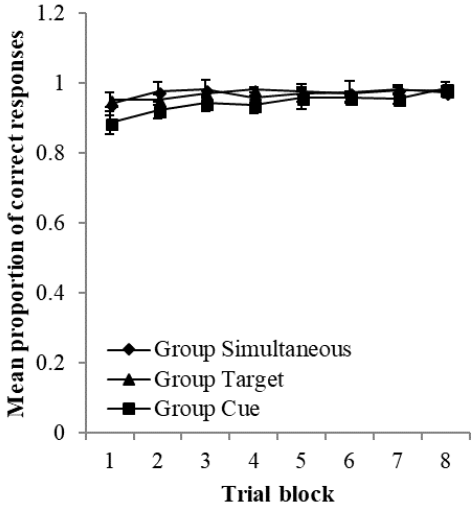


Figure 5.10a *Mean proportion of correct trials across trial blocks in Group Simultaneous, Group Target and Group Cue*

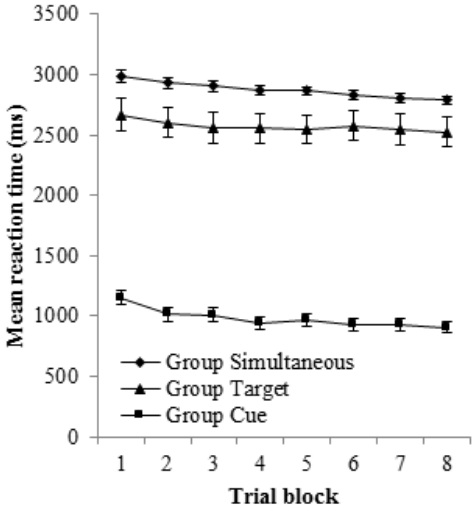


Figure 5.10b *Mean RT across trial blocks in Group Simultaneous, Group Target and Group Cue*

5.2.2.2 *Eye gaze analysis*

A three-way repeated measures ANOVA of mean proportion of dwell time with the factors of stimulus type (correlated vs. uncorrelated), trial block (1-8), and the between factor of group (Group Simultaneous vs. Group Cue vs. Group target), revealed a significant main effect of group, $F_{(2,26)} = 27.84$, $\eta_p^2 = .68$, $p < .001$, 95% CI [.20, .68], a significant main effect of trial block, $F_{(3.23,41.94)} = 3.18$, $\eta_p^2 = .20$, $p = .031$, 95% CI [NA, .45], and a non-significant main effect of stimulus type, $F_{(1,13)} = 3.47$, $\eta_p^2 = .21$, $p = .085$, 95% CI [NA, .44]. Also, a significant three-way interaction was observed, $F_{(14,182)} = 1.83$, $\eta_p^2 = .12$, $p = .037$, 95% CI [.01, .09], but no other interactions were significant, $F < 2.58$, $ps > .095$. To further investigate the interaction between stimulus type (correlated vs. uncorrelated) and trial block (1-8) within each group, three two-way repeated measures were conducted.

In keeping with the results of Experiment 9, Figure 5.11a reveals that there was no difference between the mean proportion of dwell time directed towards correlated and uncorrelated stimuli over trials in Group Simultaneous. This was confirmed by a two-way repeated measures ANOVA of mean proportion of dwell time with the factors of stimulus type (correlated vs. uncorrelated) and trial block (1-8) which revealed a non-significant main effect of stimulus type, $F_{(1,17)} = .00$, $\eta_p^2 = .00$, $p = 1.00$, 95% CI [NA, NA], a significant main effect of trial block, $F_{(7,119)} = 8.95$, $\eta_p^2 = .35$, $p < .001$, 95% CI [.20, .41], and a significant interaction, $F_{(7,119)} = 1073.30$, $\eta_p^2 = .98$, $p < .001$, 95% CI [.98, .99]. Simple main effects analysis of the interaction revealed a significant effect of stimulus type on blocks 4 and 7, smallest, $F_{(1,17)} = 5.41$, $\eta_p^2 = .24$, $p = .033$, 95%

CI [NA, .54], with firstly uncorrelated and then correlated stimuli receiving most attention. A Bayes factor was calculated for the difference between correlated and uncorrelated stimuli using an observed mean difference of .001ms, and SE was set to .001. This yielded a Bayes factor of .04, which allowed us to accept the null hypothesis, there was no difference between the proportion of dwell time directed towards correlated and uncorrelated stimuli.

Figure 5.11b reveals that there was no clear difference between the mean proportion of dwell time directed towards correlated and uncorrelated stimuli over trials in Group Target. This was confirmed by a two-way repeated measures ANOVA of mean proportion of dwell time with the factors of stimulus type (correlated vs. uncorrelated) and trial block (1-8) which revealed a non-significant main effect of stimulus type, $F_{(1,17)} = 2.52$, $\eta_p^2 = .13$, $p = .131$, 95% CI [NA, .36], trial block, $F_{(7,119)} = .75$, $\eta_p^2 = .04$, $p = .631$, 95% CI [NA, .06], and a non-significant interaction, $F_{(7,119)} = .55$, $\eta_p^2 = .03$, $p = .798$, 95% CI [NA, .03]. A Bayes factor was calculated for the difference between correlated and uncorrelated stimuli using an observed mean difference of .051 ms, and SE was set to .032. This yielded a Bayes factor of 2.14, which was inconclusive.

However, Figure 5.11c reveals that for Group Cue the mean proportion of dwell time directed towards correlated stimuli was maintained at a relatively constant level, but the mean proportion of dwell time directed towards uncorrelated stimuli decreased over trials. A two-way repeated measures ANOVA of mean proportion of dwell time with the factors of stimulus type (correlated vs. uncorrelated) and trial block (1-8) revealed a significant main effect of stimulus type, $F_{(1,15)} = 5.83$, $\eta_p^2 = 28$, $p = .029$, 95% CI [.02, .51], trial

block, $F_{(3.8,56.99)} = 2.17$, $\eta_p^2 = .13$, $p = .088$, 95% CI [NA, .22], and a non-sigificant interaction, $F_{(3.43,51.53)} = .68$, $\eta_p^2 = .04$, $p = .588$, 95% CI [NA, .10].

Also, a three-way repeated measures ANOVA of mean proportion of dwell time with the factors of stimulus type (correlated vs. uncorrelated), trial block (1-8), and the between factor of group (Group Cue vs. Group target), revealed a significant main effect of group, $F_{(1,13)} = 527.67$, $\eta_p^2 = .98$, $p < .001$, 95% CI [.99, .99], a significant main effect of trial block, $F_{(3.11,40.37)} = 8.77$, $\eta_p^2 = .40$, $p < .001$, 95% CI [07, .33], and a non-significant main effect of stimulus type, $F_{(1,13)} = .22$, $\eta_p^2 = .02$, $p = .648$, 95% CI [NA, .34]. Also, a significant interaction was observed between group and trial block, $F_{(3.11,\ 40.37)} = 8.78$, $\eta_p^2 = .40$, $p < .001$, 95% CI [07, .33], but no other interactions were significant, $F < .99$, $ps > .070$.

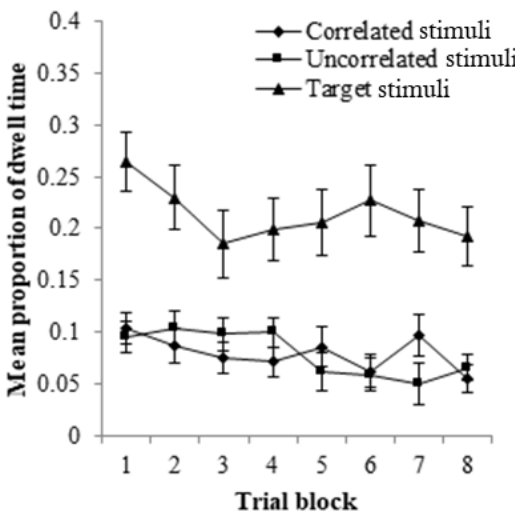


Figure 5.11a *Group Simultaneous*

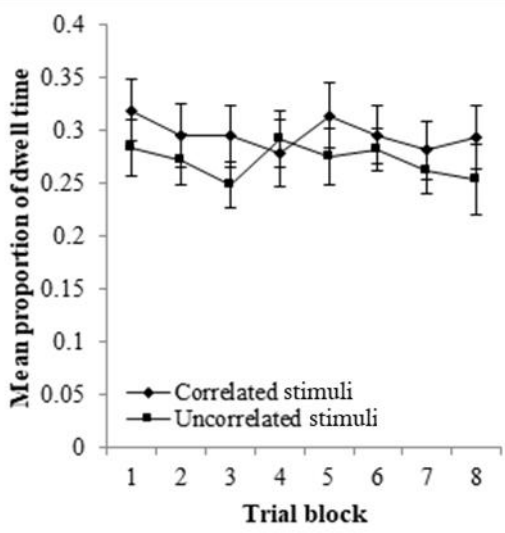


Figure 5.11b *Group Target*

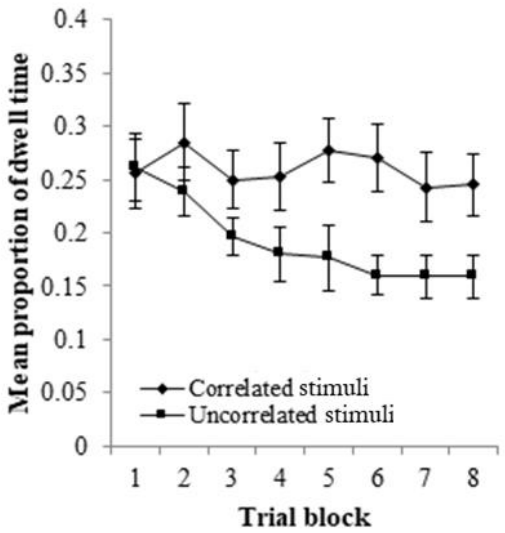


Figure 5.11c *Group Cue*

Figures 5.11 *The mean proportion of dwell time directed towards correlated, uncorrelated and target stimuli across trial blocks in a) Group Simultaneous b) Group Target c) Group Cue*

5.2.2.3 ***Probe trials***

Figure 5.12 demonstrates that correlated stimuli attracted a higher proportion of dwell time compared to uncorrelated stimuli during probes trials in Group Simultaneous, Group Target and Group Cue. A two-way repeated measures ANOVA of mean proportion of dwell time with the factors of stimulus type (correlated vs. uncorrelated), and the between factor of group (Group Simultaneous vs. Group Cue vs. Group target), revealed a significant main effect of group, $F_{(2,34)} = 3.81$, $\eta_p^2 = .18$, $p = .032$, 95% CI [NA, .21], a significant main effect of stimulus type, $F_{(1,17)} = 15.42$, $\eta_p^2 = .48$, $p = .001$, 95% CI [.08, .52], and a non-significant interaction, $F_{(2,34)} = 1.67$, $\eta_p^2 = .09$, $p = .201$, 95% CI [NA, .12]. Pre-planned paired-samples t-tests between the mean proportion of dwell time directed towards correlated and uncorrelated stimuli revealed a non-significant difference in Group Simultaneous ($t_{(17)} = 1.30$, p = .221), a non-significant

difference in Group Target ($t_{(17)}$ = 1.50, p = .153), but a significant difference during Group Cue ($t_{(17)}$ = 3.73, p = .002).

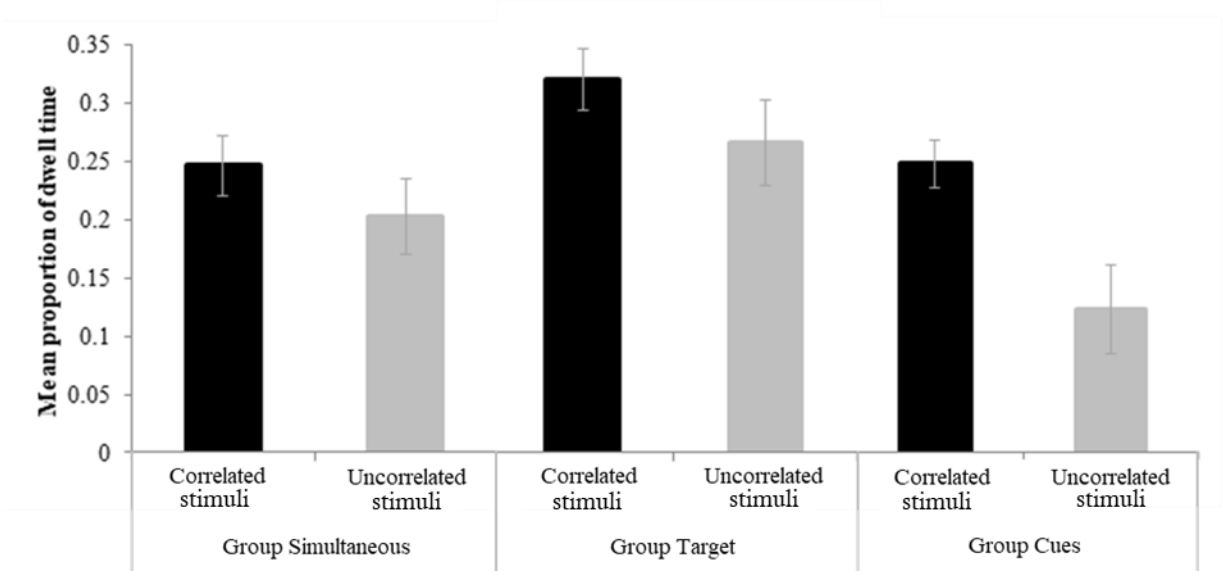


Figure 5.12 *The mean proportion of dwell time directed towards correlated and uncorrelated stimuli during probe trials in Group Simultaneous, Group Target and Group Cue*

5.2.2.4 ***Questionnaire data***

Participants completed a questionnaire which tested their understanding about the associative relationships between correlated and uncorrelated stimuli with target stimuli in the same way as described for Experiment 9. Figure 5.13 demonstrates that correlated stimuli had a larger mean difference rating in Group Simultaneous, Group Target and Group Cue. A two-way repeated measures ANOVA of mean difference rating with the factors of stimulus type (correlated vs. uncorrelated), and the between factor of group (Group Simultaneous vs. Group Cue vs. Group target), revealed a significant main effect of stimulus type, $F_{(1,35)}$ = 238.99, η_p^2 = .87, p < .001, 95% CI [.94, .96], a non-

significant main effect of group, $F_{(2,70)} = .02$, $\eta_p^2 = .001$, $p = .978$, 95% CI [NA, .23], and a non-significant interaction, $F_{(2,70)} = .18$, $\eta_p^2 = .005$, $p = .835$, 95% CI [NA, .25]. Pre-planned paired-samples t-tests investigated the difference between the mean difference rating of correlated and uncorrelated stimuli in different groups. They revealed a non-significant difference in Group Simultaneous ($t_{(17)} = 4.29$, $p < .001$), a non-significant difference in Group Target ($t_{(17)} = 4.81$, $p < .001$), but a significant difference during Group Cue ($t_{(17)} = 4.03$, $p < .001$). One-sample t-tests revealed that the mean difference ratings for the correlated stimuli were significantly greater than zero for all three groups (smallest, $t_{(35)} = 9.52$, $p < .001$), however, the difference ratings for the uncorrelated stimuli were not (largest, $t_{(35)} = .78$, $p = .439$).

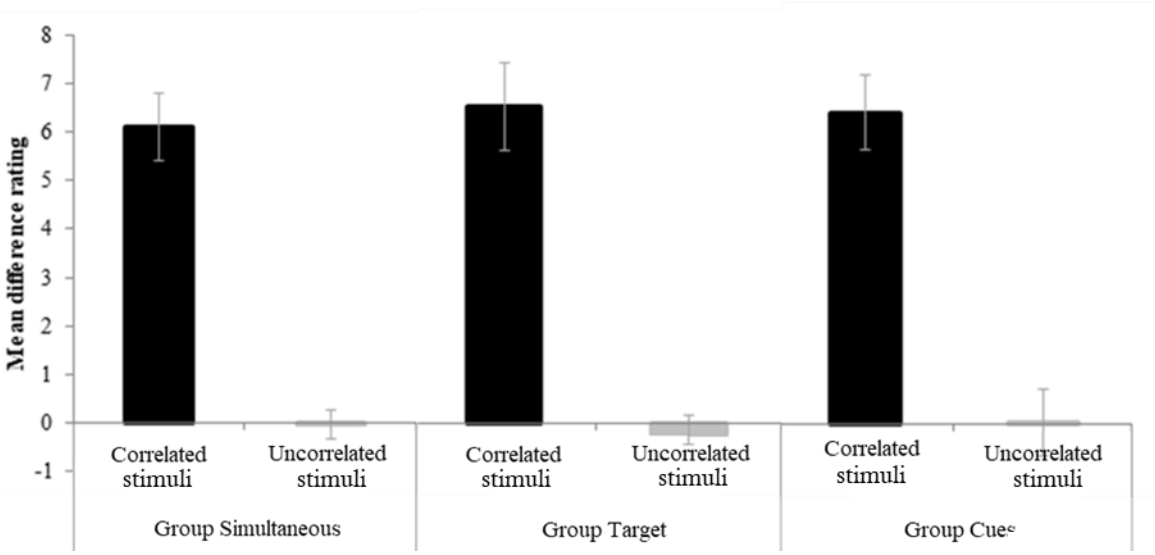


Figure 5.13 *The mean proportion of correct answers given in the questionnaire for Group Simultaneous, Group Target and Group Cue*

5.2.3 **Discussion**

The aim of Experiment 10 was two-fold. Firstly, we wanted to see whether we could replicate the findings of Experiment 9 which found that the establishment of a predictive relationship between correlated stimuli and target stimuli presented simultaneously was not sufficient to support a learned attentional bias. Secondly, we wanted to determine whether presenting correlated stimuli and target stimuli was sufficient to establish learned variations in attention, or in addition to this, participants needed to make an overt prediction about the outcome of the trial.

The findings of Experiment 10 revealed a successful replication of the results obtained in Experiment 9 because no difference in attentional bias towards correlated stimuli and uncorrelated stimuli was found in Group Simultaneous. In addition to this, there was also no learned variations in attention towards correlated or uncorrelated stimuli presented serially with target stimuli in Group Target, but a higher level of attention was maintained towards correlated stimuli in Group Cue. This finding was further supported by probe trials which revealed a significantly higher proportion of dwell time towards correlated stimuli in Group Cue only. However, from the questionnaire data it is apparent that all groups understood the associative relationship between correlated and uncorrelated stimuli with target stimuli.

The current findings suggest that associative knowledge about the relationship between a correlated stimulus and a target is not sufficient to permit the establishment of an overt attentional bias towards that stimulus. Neither is it sufficient for a predictive, sequential, relationship to be present between a

stimulus and a target in order for the stimulus to acquire an attentional bias. These observations challenge the accounts of derived attention provided by Mackintosh (1975; see also: Esber & Haselgrove, 2011; Kruschke, 2001; Le Pelley, 2004; Pearce & Hall, 1980; Pearce & Mackintosh, 2010). Instead, the results of Group Cue imply that in order for a stimulus to acquire differential overt attention, a prediction about the identity of a subsequent event must be made during the presentation of that stimulus. We shall postpone our discussion of the theoretical implications of this matter until the General Discussion of this chapter.

5.3 Experiment 11

Experiments 9 and 10 found that an attentional bias may not develop towards a stimulus correlated with a subsequent or co-present target event, even when participants had clearly learned the associative relationship between these events (Group Target and Group Simultaneous). Instead, an overt attentional bias was only established towards correlated cues when participants were asked to make a predictive response (Group Cue). It is possible, however, that attention was differentially distributed across the correlated and uncorrelated stimuli in groups Target and Simultaneous in the previous experiments, but that the testing conditions were not appropriate to reveal this bias. In other words, the conditions of training were confounded with the conditions of testing.

In order to explore this possibility, in Stage 1 of Experiment 11, participants first received identical training to that given to participants in Group Simultaneous and Group Target in Experiment 10. On the basis of the results observed in the previous experiment we expect to observe no difference in the dwell times towards the correlated and uncorrelated stimuli in this stage of the experiment. In order to determine if this training did, however, establish masked attentional biases to the correlated and uncorrelated stimuli, participants transferred to a second stage of the experiment in which the conditions of stimulus exposure and the response instructions were the same as those given to Group Cue in Experiment 10. Thus, all participants were tested under the same circumstances and also under circumstances known (from Experiment 10) to permit the detection of a learned bias in overt attention. A crucial manipulation in Stage 2 permitted us to evaluate whether any attentional bias established to

the correlated cues in Stage 1 was unexpressed. For half of the participants within each of the Serial and Simultaneous groups, the stimuli that were correlated with the target in Stage 1 remained correlated with the target in Stage 2 (and similarly the stimuli that were uncorrelated with the target in Stage 1 remained uncorrelated with the target in Stage 2) - generating groups Serial Congruent and Simultaneous Congruent. For the remaining participants within the Serial and Simultaneous groups, the stimuli that were correlated with the target in Stage 1 became uncorrelated with the target in Stage 2 (and similarly, the stimuli that were uncorrelated with the target in Stage 1 became correlated with the target in Stage 2) – generating groups Serial Incongruent and Simultaneous Incongruent. The logic being that if attention was biased towards the correlated stimuli in Stage 1, but unexpressed, then in Stage 2 this should be revealed. This should particularly be the case in the two conditions where the contingencies between the stimuli and the targets remained the same between the two stages (that is to say there would be a behavioural saving in groups Serial Congruent and Simultaneous Congruent) relative to the two groups for whom the contingencies between the stimuli and the targets were different between Stage 1 and 2. For these two groups, the prior (putatively masked) biases, should hinder the expression of the attentional bias in Stage 2.

5.3.1 **Methods**

5.3.1.1 ***Participants***

Each group contained 18 undergraduate students from The University of Nottingham who participated in return for £3 or course credit. In Group Serial

Congruent, the sample consisted of 11 females (Mean ± SD: 19.90 ± 1.51). In Group Serial Incongruent, the sample consisted of 12 females (19.83 ± 1.64). In Group Simultaneous Congruent, the sample consisted of 12 females (21.08 ± 2.11). In Group Simultaneous Incongruent, the sample consisted of 12 females (20.67 ± 3.23). Exclusion criteria for all groups were the same as in previous experiments.

5.3.1.2 *Apparatus and stimuli*

All versions of the experiment were programmed using Experiment Builder and conducted on an EyeLink 1000 Plus eye-tracker. Stimuli consisted of the letters J, P, Q, V, W and Z, which all have a similar frequency in the English language. Letters were presented in black (-1, -1, -1), size 60, Times New Roman font. Letters Q and P always served as the target stimuli, whilst letters J, V, W and Z were randomly assigned to serve as either the correlated (J & V) or uncorrelated stimuli (W & Z) (see Table 5.3 and Appendix 9 for full counterbalancing). The screen was a BenQ XL2420T LED monitor (33 × 57 cm) with resolution set to 1920 × 1080 at 114 Hz. All stimuli were presented on a white (1,1,1) background, subtended a visual angle of 25.36°, and ROI were set to 2.7 × 2.7 cm squares around stimuli.

In Stage 1, each correlated and uncorrelated stimulus was presented 36 times making 72 trials overall, divided into 4 trial blocks of 18 trials. Correlated and uncorrelated stimuli were presented 5 cm apart from each other on all trials, and appeared in random positions within the equilateral triangle. In Groups Simultaneous Congruent and Incongruent, the target was presented along with

correlated and uncorrelated stimuli; however, in Groups Serial Congruent and Incongruent, the target appeared alone in a randomised location on a second screen. In Stage 2, all stimuli were presented serially. In congruent conditions the predictive contingencies established in Stage 1 persisted into Stage 2, but in incongruent conditions these predictive contingencies were reversed. There were also 24 probe trials at the end of Stage 2 in all conditions, in which a correlated and uncorrelated stimulus were presented in the absence of a target stimulus, and participants predicted which target stimulus they thought it would have been.

Table 5.3 *Experimental design for Experiment 11*

Group	*Stage 1*	*Stage 2*	*Probes*
Simultaneous Congruent	**JWQ** **VZP** **JZQ** **VWP**	**JW→Q** **VZ→P** **JZ→Q** **VW→P**	**JW** **VZ** **JZ** **VW**
Simultaneous Incongruent	**JWQ** **VZP** **JZQ** **VWP**	**JW→P** **VZ→Q** **JZ→Q** **VW→P**	**JW** **VZ** **JZ** **VW**
Serial Congruent	**JW→Q** **VZ→P** **JZ→Q** **VW→P**	**JW→Q** **VZ→P** **JZ→Q** **VW→P**	**JW** **VZ** **JZ** **VW**
Serial Incongruent	**JW→Q** **VZ→P** **JZ→Q** **VW→P**	**JW→P** **VZ→Q** **JZ→Q** **VW→P**	**JW** **VZ** **JZ** **VW**

5.3.1.3 ***Procedure***

Eye movement data were recorded from participants' right eye. The eye-tracker was calibrated for each participant at the outset of the experimental session using a nine-point calibration, except for three participants that could only be calibrated using a five-point procedure. A brief health questionnaire was administered to screen for exclusion criteria. At the start of each experimental session, the experimenter checked that pupil and corneal reflections were present. Following this, on-screen instructions appeared: "*Thank you for participating in this study. Your first task is to focus on the dot and follow it with your eyes. Press the space bar to begin the experiment.*"

After performing the calibration, participants read further on-screen instructions for Stage 1 and Stage 2. Simultaneous conditions – In Stage 1: "*Each trial will begin with a fixation cross in the centre of the screen. This will be followed by a series of letters. Your task is to indicate whether the letter 'Q' or 'P' is present in the array. Q = left arrow, P = right arrow. Pay attention to which stimuli are paired together because at the end you will have a memory test. Press any key to start the experiment."* Serial conditions – In Stage 1: "*Each trial will begin with a fixation cross in the centre of the screen. This will be followed by a series of letters. Your task is to indicate whether the letter 'Q' or 'P' is present in the array. Q = left arrow, P = right arrow. Pay attention to which stimuli are paired together because at the end you will have a memory test. Press any key to start the experiment.*" All conditions – In Stage 2: *"In the next stage again you will see two letters followed by a target letter, but in addition to indicating its identity, this time you can anticipate whether the target will be a 'P' or a 'Q' by pressing early. Press the space bar to continue."* On probe trials: *"In the final stage of the experiment*

you will be presented with two letters but they will not be followed by a target letter. Based on these you need to guess which letter should have been paired with them. Press the space bar to continue."

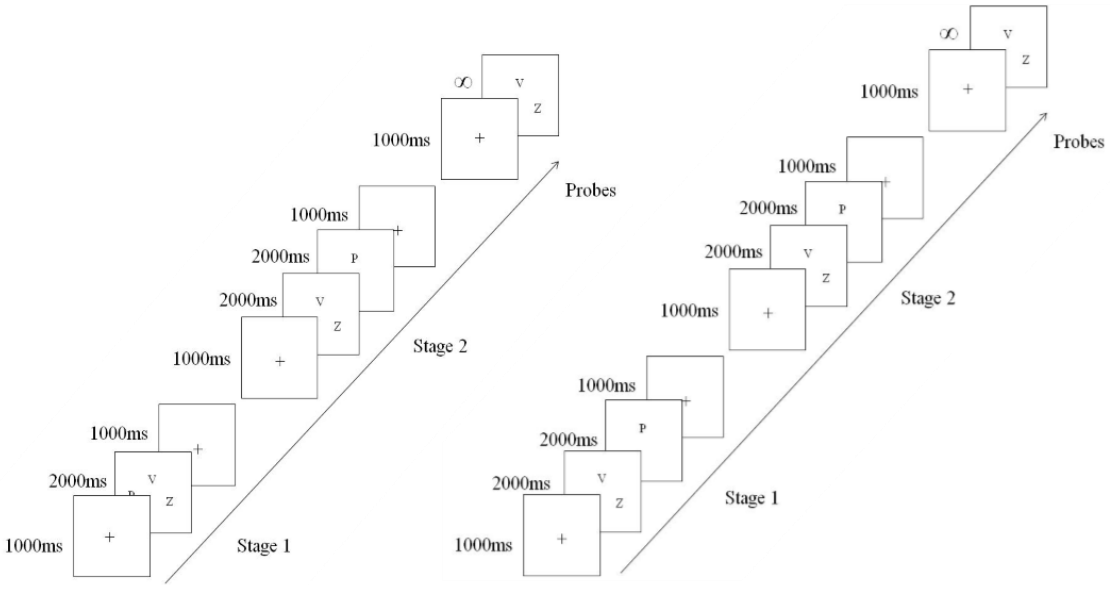


Figure 5.14 *Temporal layout of **a)** Group Simultaneous **b)** Group Target and Group Cue*

After participants completed the experiment they were given a brief questionnaire to complete which tested their understanding of the relationships between correlated and uncorrelated stimuli with the target stimuli. The questionnaire was the same one used in Experiment 9 and 10.

5.3.2 **Results**

Exclusion criteria were set to less than 60% correct responses across all trial blocks (zero participants were excluded on this basis), and greater than 20% missing eye-tracking data (zero participants were excluded on this basis). For

subsequent analysis Greenhouse-Geisser corrections were applied where sphericity was violated.

STAGE 1

5.3.2.1 ***Behavioural data***

Figure 5.15a reveals that in Stage 1 for Group Simultaneous Congruent and Group Simultaneous Incongruent, the mean proportion of correct responses was high from block 1, and therefore only increased slightly over the course of the experiment. Figure 5.15b reveals that in Stage 1 of Group Serial Congruent and Group Serial Incongruent, the mean proportion of correct trials was also high from block 1, and again increased only slightly over the course of the experiment. A three-way mixed measures ANOVA of individual proportions of correct responses with the within factor of trial block (1-4), and between factors of group (simultaneous vs. serial) and congruency (congruent vs. incongruent), revealed a significant main effect of trial block, $F_{(3,102)} = 3.50$, $\eta_p^2 = .09$, $p = .018$, 95% CI [.01, .17], and group, $F_{(1,68)} = 6.29$, $\eta_p^2 = .09$, $p = .015$, 95% CI [NA, .70], a non-significant main effect of congruency, $F_{(1,34)} = .01$, $\eta_p^2 = .00$, $p = .918$, 95% CI [NA, .06], a significant interaction between block * congruency, $F_{(3,102)} = 3.60$, $\eta_p^2 = .10$, $p = .016$, 95% CI [.01, .17], all remaining interactions were non-significant, largest, $F_{(3,102)} = .55$, $\eta_p^2 = .02$, $p = .652$, 95% CI [NA, .05]. Simple main effects analysis of the interaction between block and congruency revealed that the only significant difference between Group Congruent and Group

Incongruent was in block 4, $F_{(1,68)} = 4.40$, $\eta_p^2 = .06$, $p = .040$, 95% CI [NA, .32], with Group Incongruent having the highest proportion of correct responses.

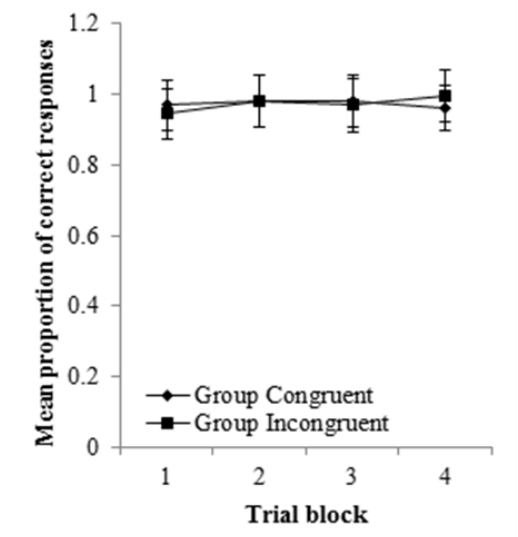


Figure 5.15a *Group Simultaneous*

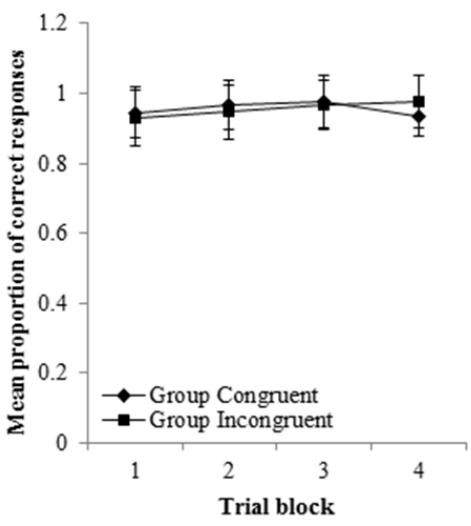


Figure 5.15b *Group Serial*

Figures 5.15 *Mean correct responses across 4 trial blocks during Stage 1* ***a)*** *Group Simultaneous* ***b)*** *Group Serial*

Figures 5.16a and 5.16b reveal that in Stage 1, the mean RT decreased slightly for the simultaneous and serial groups. A three-way mixed measures ANOVA of individual RT with the within factor of trial block (1-4), and between factors of group (simultaneous vs. serial) and congruency (congruent vs. incongruent), revealed a significant main effect of trial block, $F_{(3,102)} = 13.80$, $\eta_p^2 = .29$, $p < .001$, 95% CI [.06, .34], group, $F_{(1,34)} = 4.47$, $\eta_p^2 = .12$, $p = .042$, 95% CI [NA, .32], a trend-level main effect of congruency, $F_{(1,34)} = 3.96$, $\eta_p^2 = .10$, $p = .055$, 95% CI [NA, .31], a significant interaction between congruency * group, $F_{(1,34)} = 6.54$, $\eta_p^2 = .16$, $p = .015$, 95% CI [NA, .37], block * group, $F_{(3,102)} = 3.04$, $\eta_p^2 = .08$, $p = .033$, 95% CI [NA, .18], congruency * block, $F_{(3,102)} = 11.10$, $\eta_p^2 =$

.25, $p < .001$, 95% CI [.10, .36], and a significant three-way interaction, $F_{(3,102)} = 3.60$, $\eta_p^2 = .25$, $p = .016$, 95% CI [.00, .19]. Simple main effects analysis of the interaction between congruency and group revealed a significant difference in RT between Group Congruent and Group Incongruent in Group Serial only, $F_{(1,34)} = 13.50$, $\eta_p^2 = .44$, $p = .002$, 95% CI [.06, .31], with Group Congruent having the shortest RT.

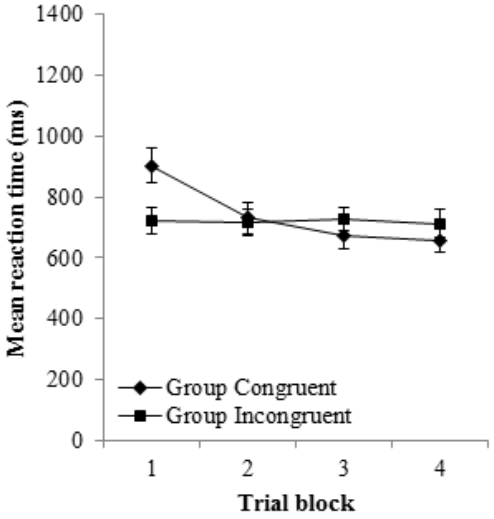


Figure 5.16a *Group Simultaneous*

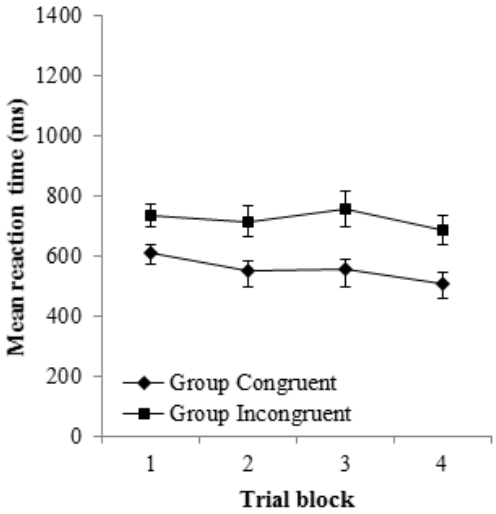


Figure 5.16b *Group Serial*

Figures 5.16 *Mean RT across 4 trial blocks during Stage 1* ***a)*** *Group Simultaneous* ***b)*** *Group Serial*

5.3.2.2 *Eye gaze analysis*

In keeping with the results of Experiment 10, Figures 5.17a, 5.17b, 5.17c and 5.17d demonstrate that there is no clear difference between the mean proportion of dwell time directed towards the correlated and uncorrelated stimuli for any of the groups over the trial blocks of Stage 1. A four-way mixed measures ANOVA of mean proportion of dwell time with the within factors of

trial block (1-4) and stimulus type (correlated vs. uncorrelated), and between factors of group (simultaneous vs. serial) and congruency (congruent vs. incongruent) revealed a significant main effect of group, $F_{(1,34)} = 68.16$, $\eta_p^2 = .67$, $p < .001$, 95% CI [.52, .88], all remaining main effects and interactions were non-significant (largest $F_{(1,34)} = 2.23$, $\eta_p^2 = .06$, $p = .144$, 95% CI [NA, .58]).

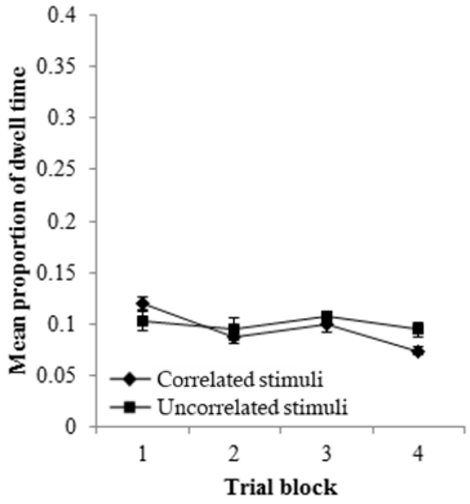


Figure 5.17a *Group Simultaneous Congruent*

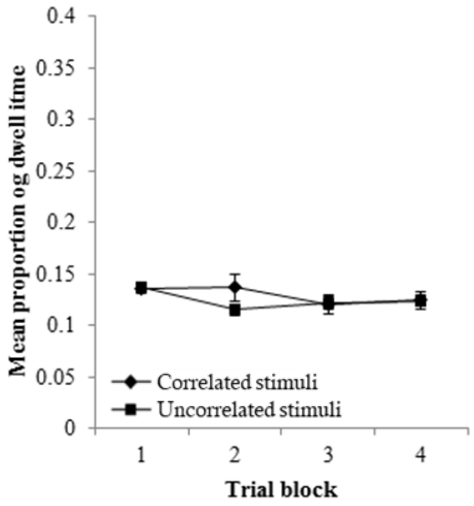


Figure 5.17b *Group Simultaneous Incongruent*

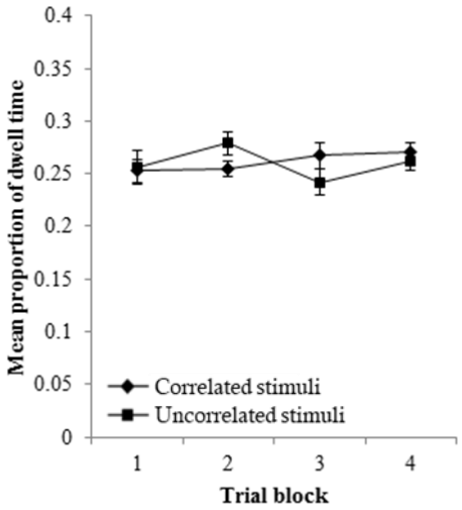


Figure 5.17c *Group Serial Congruent*

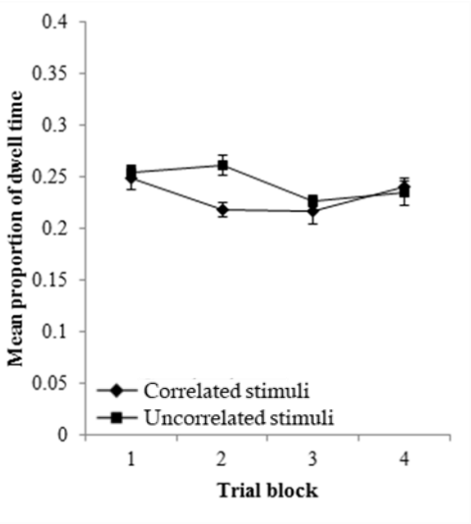


Figure 5.17d *Group Serial Incongruent*

Figures 5.17 *Mean proportion of dwell time directed towards predictive and irrelevant cues across 4 trial blocks during Stage 1* ***a)*** *Group Simultaneous Congruent* ***b)*** *Group Simultaneous Incongruent* ***c)*** *Group Serial Congruent* ***d)*** *Group Serial Incongruent*

STAGE 2

5.3.2.3 *Behavioural data*

Figures 5.18a and b show the mean proportion correct responses for the four groups during Stage 2. Performance improved across the four blocks of training, and across the majority of these blocks, accuracy was superior in the congruent groups, regardless of serial or successive training in Stage 1. A three-way mixed measures ANOVA of mean proportion correct responses with the within factor of trial block (1-4), and between factors of group (simultaneous vs. serial) and congruency (congruent vs. incongruent), revealed a significant main effect of trial block, $F_{(3,93)} = 26.70$, $\eta_p^2 = .46$, $p < .001$, 95% CI [.30, .56], group, $F_{(1,31)} = 6.42$, $\eta_p^2 = .17$, $p = .017$, 95% CI [.00, .39], congruency, $F_{(1,31)} = 15.04$, $\eta_p^2 = .33$, $p = .001$, 95% CI [.08, .52], a significant interaction between block * group, $F_{(3,93)} = 3.58$, $\eta_p^2 = .10$, $p = .017$, 95% CI [.00, .39], block * congruency,

$F_{(2.41,74.57)}$ = 4.39, η_p^2 = .12, p = .011, 95% CI [.01, .25], a non-significant interaction between, congruency * group, $F_{(1,31)}$ = .05, η_p^2 = 002, p = .822, 95% CI [NA, .11], and a non-significant three-way interaction, $F_{(3,93)}$ = 1.66, η_p^2 = .05, p = .182, 95% CI [NA, .13]. Simple main effects analysis of the interaction between block and group revealed that the difference in proportion of correct responses during Group Simultaneous and Group Serial was significant in block 1 and 2, smallest, $F_{(3,93)}$ = 6.90, η_p^2 = .33, p = .020, 95% CI [.03, .53], with Group Simultaneous having a higher proportion of correct responses. Simple main effects analysis of the interaction between block and congruency revealed that the difference in proportion of correct responses for Group Congruent and Group Incongruent was significant in block 1, 2 and 3 smallest, $F_{(2.41,74.57)}$ = 11.01, η_p^2 = .44, p = .005, 95% CI [.10, .35], with Group Congruent having a higher proportion of correct responses. This final interaction confirms that our manipulation of congruency was successful between Stage 1 and 2.

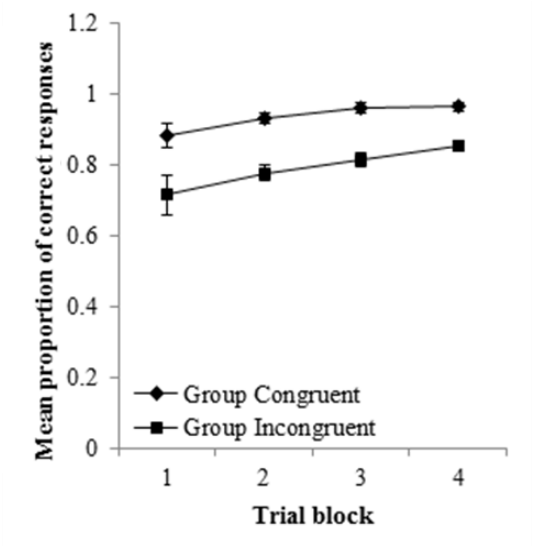


Figure 5.19a *Group Simultaneous*

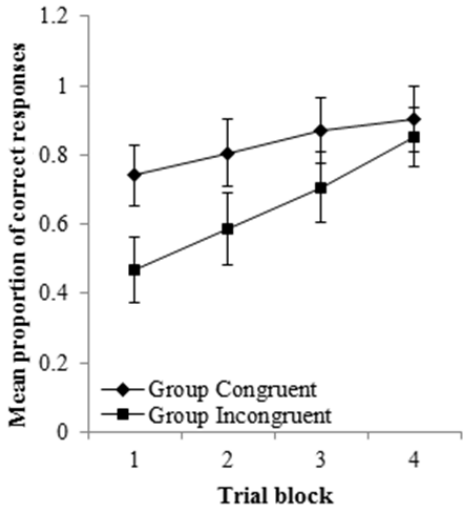


Figure 5.19b *Group Serial*

Figures 5.19 *Mean correct responses across 4 trial blocks during Stage 2* ***a)*** *Group Simultaneous* ***b)*** *Group Serial*

Figures 5.20a and 5.20b reveal that in Stage 2, the mean RT decreased for the simultaneous and serial conditions, but was fastest for the congruent conditions, again confirming that switching the contingency of the relevant stimuli was effective, and that participants sensitive to the difference in congruency of the stimuli during Stage 1 of the experiment. A three-way mixed measures ANOVA of mean RT with the within factor of trial block (1-4), and between factors of group (simultaneous vs. serial) and congruency (congruent vs. incongruent) revealed a significant main effect of, trial block, $F_{(2.01,58.19)} = 4.30$, $\eta_p^2 = .13$, $p = .018$, 95% CI [.02, .31], group, $F_{(1,29)} = 5.54$, $\eta_p^2 = .16$, $p = .026$, 95% CI [.10, .56], congruency, $F_{(1,29)} = 13.03$, $\eta_p^2 = .31$, $p = .001$, 95% CI [.06, .52], a significant interaction between block * group, $F_{(3,87)} = 4.30$, $\eta_p^2 = .13$, $p = .007$, 95% CI [.01, .24], but all other interactions were non-significant, largest, $F_{(1,29)} = 1.26$, $\eta_p^2 = .04$, $p = .270$, 95% CI [NA, .12]. Simple main effects analysis of the interaction between block and group revealed that the difference in RT between

Group Simultaneous and Group Serial was significant in block 1, 2, 3 and 4, smallest, $F_{(3,87)} = 5.73$, $\eta_p^2 = .29$, $p = .031$, 95% CI [NA, .53], with Group Simultaneous having a shorter RT.

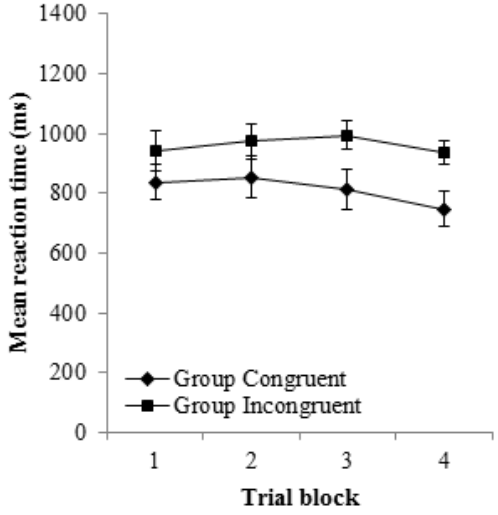


Figure 5.20a *Group Simultaneous*

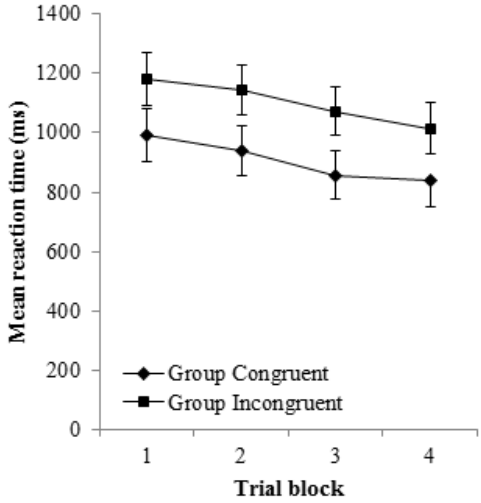


Figure 5.20b *Group Serial*

Figures 5.20 *Mean RT across 4 trial blocks during Stage 2* ***a)*** *Group Simultaneous* ***b)*** *Group Serial*

5.3.2.4 *Eye gaze*

Figures 5.21a, 5.21b, 5.21c and 5.21d illustrate that a larger proportion of dwell time was directed towards the correlated stimuli in all groups in Stage 2, irrespective of whether participants were in the congruent of incongruent groups, or whether training in Stage 1 was conducted using a serial or simultaneous procedure. A four-way mixed measures ANOVA of mean proportion of dwell time with the within factors of trial block (1-4) and stimulus type (correlated vs. uncorrelated), and between factor of group (simultaneous vs. serial) and congruency (congruent vs. incongruent) revealed a significant main effect of

block, $F_{(2.27,77.24)}$ = 7.70, η_p^2 = .19, p = .001, 95% CI [.04, .32], stimulus type, $F_{(1,34)}$ = 17.90, η_p^2 = .35, p < .001, 95% CI [.10, .53], group, $F_{(1,34)}$ = 4.62, η_p^2 = .12, p = .039, 95% CI [NA, .32], a non-significant effect of congruency, $F_{(1,34)}$ = 3.30, η_p^2 = .09, p = .078, 95% CI [NA, .29]. There was a significant block * stimulus type, $F_{(3,102)}$ = 3.19, η_p^2 = .09, p = .027, 95% CI [NA, .18] interaction, but all remaining interactions were non-significant, largest $F_{(1,34)}$ = 2.61, η_p^2 = .07, p = .116, 95% CI [NA, .11].

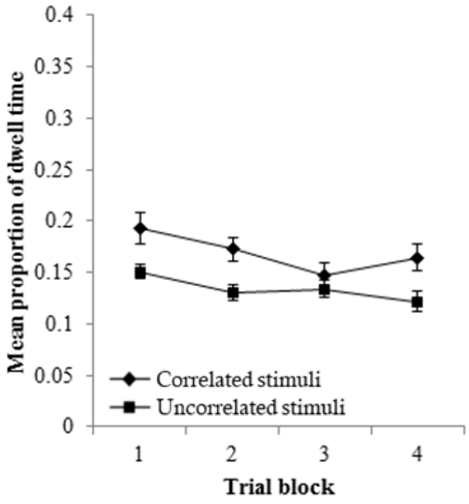


Figure 5.21a *Group Simultaneous Congruent*

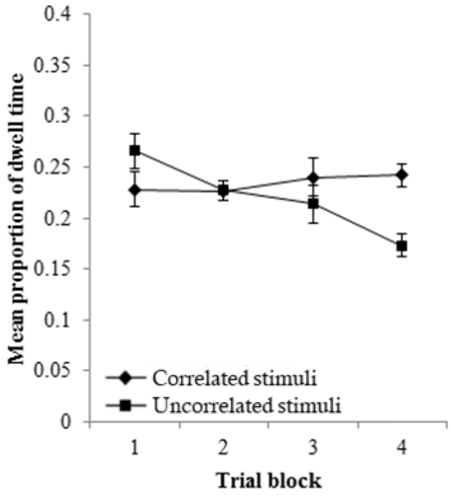


Figure 5.21b *Group Simultaneous Incongruent*

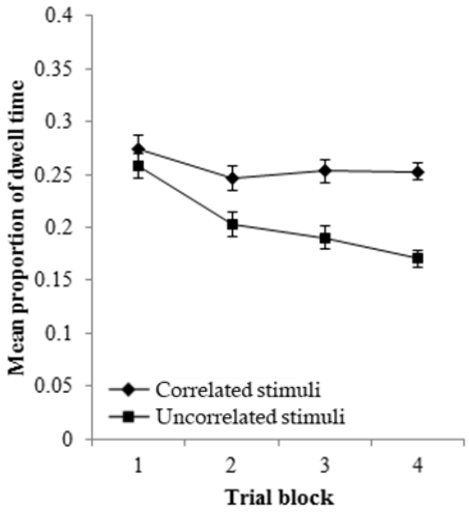


Figure 5.21c *Group Serial Congruent*

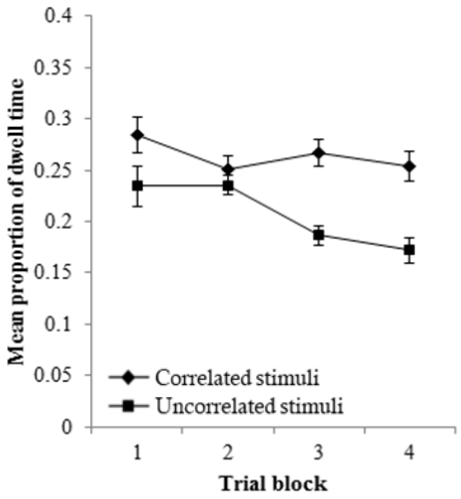


Figure 5.21d *Group Serial Incongruent*

Figures 5.21 *Mean proportion of dwell time directed towards correlated and uncorrelated cues across 4 trial blocks during Stage 2* ***a)*** *Group Simultaneous Congruent* ***b)*** *Group Simultaneous Incongruent* ***c)*** *Group Serial Congruent* ***d)*** *Group Serial Incongruent*

5.3.2.5 ***Probe trials***

Figures 5.22a and 5.22b show that incongruent trials attracted a higher proportion of dwell time compared to congruent trials, perhaps reflecting the uncertainty associated with them. Also, correlated stimuli attracted the largest proportion of dwell time. A two-way repeated measures ANOVA of mean proportion of dwell time with the within factor of stimulus type (correlated vs. uncorrelated) and between factor of congruency (congruent vs. incongruent) revealed a significant main effect of congruency, $F_{(1,34)} = 13.26$, $\eta_p^2 = .28$, $p = .001$, 95% CI [.06, .48], stimulus type, $F_{(1,34)} = 24.08$, $\eta_p^2 = .42$, $p < .001$, 95% CI [.16, .59], all interactions were non-significant, largest, $F_{(1,34)} = 2.51$, $\eta_p^2 = .07$, $p = .123$, 95% CI [NA, .26].

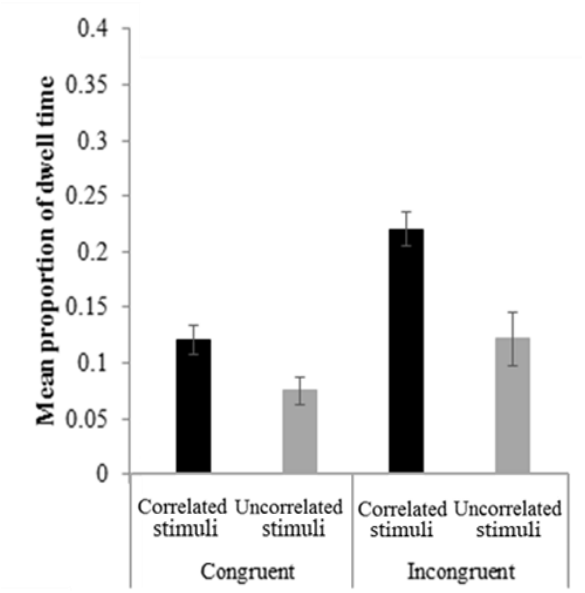


Figure 5.22a *Mean proportion of dwell time directed towards correlated and uncorrelated cues in Simultaneous Congruent and Simultaneous Incongruent groups on probe trials*

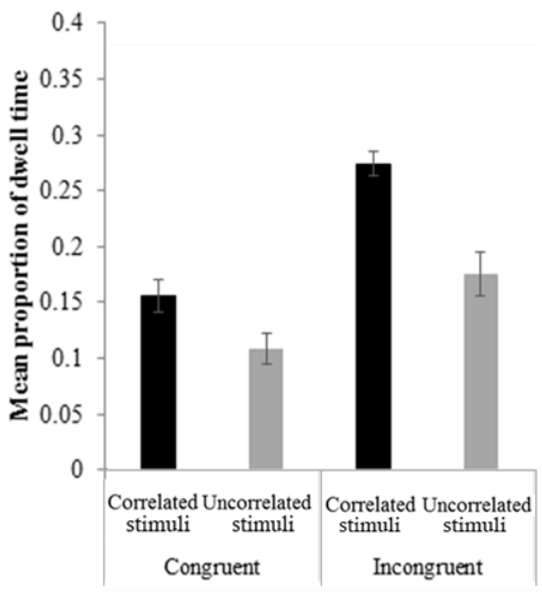


Figure 5.22b *Mean proportion of dwell time directed towards correlated and uncorrelated cues in Serial Congruent and Serial Incongruent groups on probe trials*

5.3.2.6 *Questionnaire data*

Participants completed a questionnaire which tested their understanding about the associative relationship between correlated and uncorrelated stimuli with target stimuli. The scores were calculated in a manner identical to Experiment 9, by subtracting the score for the pairings (UY-UZ, VY-VZ, WY-WZ, XY-XZ) from each other to give the difference rating, and plotted in Figure 5.27a for Group Simultaneous Congruent and Simultaneous Incongruent, and Figure 5.27b for Group Serial Congruent and Serial Incongruent. A three-way repeated measures ANOVA of mean difference rating with the within factor of stimulus type (correlated vs. uncorrelated) and between factors of group (simultaneous vs. serial) and congruency (congruent vs. incongruent) revealed a significant main effect of stimulus type, $F_{(1,34)} = 686.25$, $\eta_p^2 = .99$, $p = .024$, 95%

CI [.76, .98], a non-significant main effect of group, $F_{(1,34)} = 2.27$, $\eta_p^2 = .69$, $p = .373$, 95% CI [NA, .58], and congruency, $F_{(1,34)} = .61$, $\eta_p^2 = .06$, $p = .579$ 95% CI [NA, .03], all interactions were non-significant, largest, $F_{(1,34)} = 48.96$, $\eta_p^2 = .42$, $p = .090$, 95% CI [.51, .48].

For Group Simultaneous Congruent, the mean difference rating was significantly above zero for correlated stimuli ($t_{(35)} = 28.06$, $p < .001$), but not uncorrelated stimuli ($t_{(17)} = 1.46$ $p = .163$). For Group Simultaneous Incongruent, the mean difference rating was significantly above zero for correlated stimuli, ($t_{(17)} = 8.74$, $p < .001$), and uncorrelated stimuli ($t_{(17)} = 3.23$, $p = .005$). For Group Serial Congruent, the mean difference rating was significantly above zero for correlated stimuli ($t_{(17)} = 10.73$, $p < .001$), and uncorrelated stimuli ($t_{(17)} = 2.50$, $p = .023$). For Group Serial Incongruent, the mean difference rating was significantly above zero for correlated stimuli ($t_{(17)} = 7.41$, $p < .001$), and uncorrelated stimuli ($t_{(17)} = .5.29$, $p < .001$).

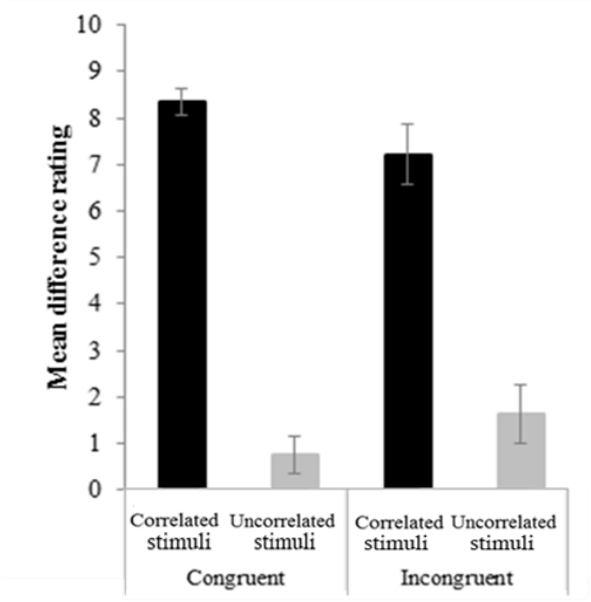


Figure 5.23a *Mean rating score for correlated and uncorrelated cues in Simultaneous Congruent and Simultaneous Incongruent groups on the questionnaire*

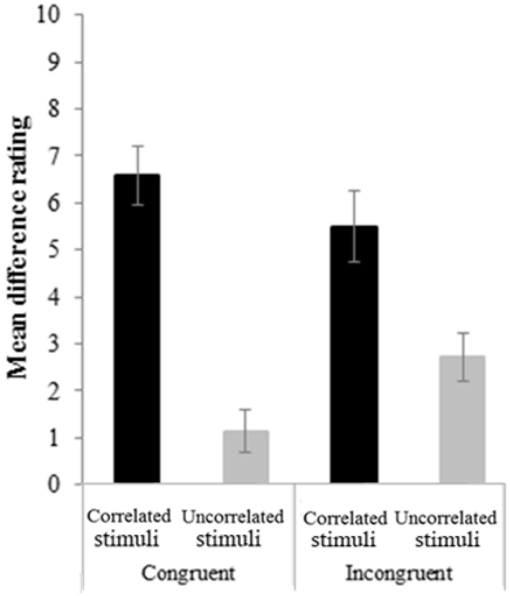


Figure 5.23b *Mean rating score for correlated and uncorrelated cues in Serial Congruent and Serial Incongruent groups on the questionnaire*

5.3.3 **Discussion**

In line with previous experiments, Experiment 11 found no overt attentional bias towards correlated stimuli presented simultaneously or serially with target stimuli in the absence of prediction during Stage 1. Upon being subsequently transferred into a training condition that favoured the establishment of attentional biases between the correlated and uncorrelated stimuli in Stage 2, it was revealed that dwell times towards the congruent stimuli were longer than towards the incongruent stimuli in both the simultaneous and serial groups. Crucially, this was the case when the predictive contingencies of the correlated and uncorrelated stimuli were the same between Stages 1 and 2 or switched. This result is consistent with the suggestion that no differences in attention were acquired to the correlated and uncorrelated stimuli in Stage 1.

One objection to this conclusion might be that the congruency manipulation may not have been effective – perhaps participants were simply not learning about the correlated and uncorrelated stimuli in Stage 1 and simply attending to the target stimulus on each trial. This possibility is rendered unlikely from the observation of main effects of congruency in Stage 2 for all measures reported.

One particularly interesting observation in the current experiment was the observation that, overall, dwell times were longer in the incongruent groups than the congruent groups in Stage 2. This result is consistent with the idea that a surprising change in the outcome of a trial may sustain, or re-establish overt attention. That is to say, we appear to observe an effect that is consistent with the Pearce-Hall (1980) theory. At the outset of Stage 2, the target changes for every single trial type in the two incongruent groups. This manipulation should engender a substantial prediction error on these trials and restore attention to the cues. There are relatively few demonstrations of this effect in human participants; however, one is negative transfer (Griffiths, Johnson & Mitchell, 2011). This study used the allergist task (described previously) where participants are required to anticipate whether Mr X will experience any ill effects from eating certain pairs of foods. However, in this version, in Stage 1 the target cue was paired with an outcome of moderate strength, but in Stage 2 the strength of the target it was paired with increased. Results revealed that learning about this second cue → strong outcome pairing was slower, since it was established as predictive in Stage 1 and therefore attention towards it decreased. Moreover, it was found that the effect could be abolished if participants were given a surprising extinction trials in-between the cue → moderate outcome and cue → strong outcome training.

Experiment 11 implies that associative strength, or relative differences in associative strength, are not sufficient for learned changes in overt attention to develop as suggested by numerous models of associative learning (e.g. Mackintosh, 1975; Le Pelley, 2004; Esber & Haselgrove, 2011). Learned changes in overt attention are not incidental, instead they need to provide 'information' and therefore a stimulus's predictive value is crucial – 'learned predictiveness' is an apt term for the phenomenon.

5.4 General discussion

Chapter 5 explored whether an attentional bias would develop to stimuli that were correlated with task relevant targets in the presence and absence of predictive relationships. Experiment 9 presented congruent and incongruent stimuli simultaneously with target stimuli. Experiment 10 presented congruent and incongruent cues serially with target stimuli, but only Group Cue was encouraged to predict the identity of target stimuli before they appeared. Finally, Experiment 11 had different groups who experienced simultaneous or serial presentations with either a congruent or incongruent shift from Stage 1 to Stage 2. All experiments revealed that association alone was not sufficient to establish an overt attentional bias towards correlated stimuli and away from uncorrelated stimuli. It was clear from the questionnaire data that participants had learned the associative relationship between stimuli in all experiments, and yet only when participants were required to make an active prediction about the subsequent target identity did an overt attentional bias develop. These results are consistent with the notion that in order for stimuli to acquire different degrees of attentional capture, they must be established as being in a *predictive* relationship with a target outcome. This conclusion was strengthened by, Group Cue in Experiment 10 and Stage 2 in Experiment 11, which found an attentional bias towards correlated stimuli. During these conditions participants in Group Target and Group Cue experienced an identical associative relationship between correlated and uncorrelated stimuli with target stimuli, but only participants in Group Cue were permitted to make a prediction regarding the outcome of the trial.

The findings in Chapter 5 imply a dissociation between the predictive relevance of a stimulus and participants' knowledge of the associative relationship between the stimulus and target. Currently, none of the attentional models of associative learning (e.g. Esber & Haselgrove, 2011; Kruschke, 2001; Le Pelley, 2004; Mackintosh, 1975; Pearce & Hall, 1980; Pearce & Mackintosh, 2010) make a distinction between associative strength and prediction, and consequently would find it difficult to explain our current series of results. This is assumed in casual analyses of the learned predictiveness effect, but not in associative learning models which only refer to changes in attention and changes in associative strength.

Additional shortcomings of this paradigm include, that participant's performance on the task was likely to have been influenced by motivation. Since all trials were a set length, regardless of the response made by participant's, motivation was likely to have been low and this may have masked differences in attentional allocation. To rectify this problem, a future experiment could reward correct responses with a monitory reinforcer that was tallied at the end of each trial. Another potential confound was that there might have been an effect of instruction because participants were only told to remember which letters were paired together, and this is not likely to have required an overt shift in attention.

Together, the results in Chapter 5 suggest that a correlation between a stimulus and a target outcome is insufficient for the establishment of an attentional bias. Previously it had been assumed that contingency (probabilistic relationship between a stimulus and an event) and spacio-temporal contiguity (proximity) were necessary and sufficient to produce associations, and from this a change in attention (Gormezano & Kehoe, 1975). However, the experiments

described in Chapter 5 suggest that in order to bias attention the stimulus needs to provide 'information' – its predictive value is crucial.

5.5 Conclusion

The experiments in Chapter 5 suggest that in order for an attentional bias to develop, a stimulus needs to, firstly, to be predictive about the outcome, and secondly, have high associative strength. These results, and others which emphasise predictive validity, cannot be explained using current attentional models of associative learning because they do not include a distinction between associative strength and prediction.

Chapter 6:

Overall discussion

The aim of the current thesis was to investigate the role of selective attention during learned contingency tasks and to relate these findings to current associative learning models. Chapter 2 measured eye gaze during a learned predictiveness task (AV → O1, AW → O1, BV → O2, BW → O2, CX → O2, CY → O2, DX → O1, DY → O1) and revealed an attentional bias towards predictive cues using a range of eye gaze measures, including: dwell time, proportion of dwell time, fixation count and proportion of fixation count. An attentional bias was not exhibited in the time it took participants to make their first fixation into either ROI, and consequently latency to first fixation was poorly correlated with the other measures of attention, and did not distinguish between cues that were predictive or irrelevant to the solution of the task. This result is consistent with the idea that learned changes in attention are expressed in a reasonably overt manner. If the predictive cue had acquired the capacity to attract attention covertly more rapidly than the irrelevant cue then we would have expected latencies to first fixation to be more rapid to this cue. This implies that using our paradigm, latency to first fixation does not tap into the same attentional construct, but the other measures used (except fixation omission) were comparable. This is important since previous learned predictiveness experiments have used these measures interchangeably (Dwell time: Le Pelley et al., 2011. Proportion of dwell time: Le Pelley et al. 2013; Mitchell et al., 2012. Fixation count: Beesley et al., 2015. Proportion of fixation count: Beesley et al., 2015).

Chapter 2 also revealed a number of theoretical implications. Firstly, it was found that the acquisition of the task proceeded at a faster rate than the acquisition of selective attention. This is an interesting finding because it implies

that the transfer of information from the learning mechanism to the attentional mechanism is not perfect. The purpose of this lag in attention might be to keep learning conservative, to prevent the attribution of high levels of salience to a cue for which only limited information has been acquired. It was also discovered that eye gaze towards predictive and irrelevant stimuli was influenced by prediction success. If the previous trial was incorrect, there was little evidence for variations in attention. This provides support for the model of associative learning proposed by Mackintosh (1975) which predicts that associability will increase towards the best available predictor of reinforcement. It does not lend support for the Pearce-Hall (1980) model which predicts that a cue's associability will increase if it is uncertainly paired with an outcome.

Chapter 2 also investigated the role of certainty and uncertainty within the learned predictiveness task. On certain trials, Experiments 1, 2 and 3 found that participants directed increasingly more attention towards predictive cues compared to irrelevant cues. This finding provides support for the model of associative learning proposed by Mackintosh (1975) which claims that more attention will be directed towards cues that are the best predictor of an outcome. The same pattern of results was observed during learned predictiveness tasks that incorporated a degree of uncertainty; but in addition, Experiment 3 also revealed that overall more attention was directed towards uncertain trials compared to certain trials. Moreover, using a similar methodology to that used by Hogarth et al. (2008), Experiment 2 revealed that the difference between the amount of attention captured by cue X in BX, was larger than cue X in AX or CX. Conversely, these findings provide support for the Pearce-Hall (1980) model

which claims that most attention will be directed towards cues whose relationship with the outcome is uncertain.

Taken together the findings of Experiments 1, 2 and 3 suggest that at a within-trial-level selective attention during associative learning functions according to the model proposed by Mackintosh (1975); however, at a between-trial-level it functions according to the principles put forward in the Pearce-Hall (1980) model. This demonstrates that neither model can predict attentional allocation under conditions of certainty and uncertainty. In order to combat this problem Le Pelley (2004) proposed a hybrid model of associative learning which incorporated the Mackintosh mechanism and Pearce-Hall mechanism into a single model. It does this by claiming that there are two different types of attention (exploitative & explorative) which combine to determine a cue's overall salience. This model explains the learned predictiveness effect on certain trials by suggesting that a cue's attentional associability will increase towards predictive cues because they are better predictors of the outcome compared to irrelevant cues. On the other hand, a cue's salience associability will be low because the outcome is fully expected as the cue is a good predictor of the outcome. However, on uncertain trials a cue's salience associability will be higher because the outcome is unpredictable.

By incorporating aspects of the Mackintosh (1975) and Pearce-Hall (1980) models into a hybrid model, Le Pelley's (2004) model is able to explain a wide range of phenomena; however, Pearce and Mackintosh (2010) argued that it ignores the inherent contradiction between the two models, and is not a parsimonious account of associative learning. An alternative model that can also explain the findings of Experiments 1, 2 and 3 was proposed by Esber-

Haselgrove (2011), which reconciles the influence of predictiveness and uncertainty into a single mechanism for attentional allocation. This model promotes enhanced attention towards predictive cues over irrelevant cues, but can also account for the superiority of uncertain trials by arguing that they enter into multiple associations (e.g. cue → O1 & cue → O2). The model determines how much attention a cue will attract by summing the absolute associative strength for all associations, and therefore, uncertain trials attract more attention than certain cues.

Chapter 3 expanded our findings about the learned predictiveness effect to determine whether the change in associability observed in IDS/EDS experiments was underpinned by a shift in attention that generalises from Stage 1 into Stage 2. In Stage 1, Experiments 4 and 5 both revealed that participants developed an attentional bias towards predictive cues when the predictive contingency was 100%. This finding echoes Chapter 2, and provides support for the Mackintosh (1975) model. However, unlike Chapter 2, this attentional bias was not observed when the predictive contingency was reduced to 75%.

In Stage 2 of the IDS conditions, participants directed more attention towards predictive cues from the outset suggesting that they had transferred the attentional bias acquired in Stage 1. In the EDS conditions, participants also transferred their attentional bias into Stage 2 meaning that they were directing more attention towards newly irrelevant cues; however, this bias was only maintained for 2 or 3 trials before participants shifted their attention towards the newly predictive cues which were irrelevant in Stage 1. This provides the first direct evidence that an attentional bias was created in Stage 1 of an IDS/EDS task, which was generalised into Stage 2 at the start of IDS and EDS conditions.

In addition, it also demonstrates how sensitive human participants are to trial feedback, only requiring two or three error signals before shifting their attention. These findings suggest that similarly to associability, attention generalises between Stage 1 and Stage 2; but the reduction in the amount of attention directed towards predictive cues, and increase in the amount of attention directed towards irrelevant cues at the start of Stage 2 highlights that this generalisation was not perfect across the context shift – like associability.

The traditional account of generalisation is that a CR which was originally elicited by a cue, is also elicited by a cue with elements in common (Atkinson & Estes, 1963; Mackintosh 1974; Rescorla, 1976). The extent to which two cues are deemed to be similar is not just based on their intrinsic properties, but also their associative history (Honey & Hall, 1989). Honey and Hall found that a cue's acquired equivalence (based on associative history) leads to enhanced generalisation, and acquired distinctiveness reduces it. According to this hypothesis, cues that were paired with O1 in Stage 1 and Stage 2 would have more elements in common than cues that were paired with O1, then O2. Although, the usefulness of this interpretation is limited because it does not posit a role for attention.

In Chapter 4 we expanded the types of participants that the learned predictiveness effect had been demonstrated in. The majority of research which provides support for the Mackintosh (1975) model, and therefore the learned predictiveness effect, has come from studies using adult human participants (see: Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al.,

2012). However, much of the research that provides support for the Pearce-Hall (1980) model has been found using animal participants (see: Dickinson, Hall & Mackintosh, 1976; Haselgrove, Esber, Pearce & Jones, 2010; Kaye & Pearce, 1984; Swan & Pearce, 1988; Wilson, Boumphrey & Pearce, 1992). Despite this inconsistency, there had been no back-translation of the methodology used during learned predictiveness tasks into children or animals to determine whether the effect exclusively provided support for the Mackintosh (1975) model, or whether the attentional bias observed resulted from the methodology used to test participants.

Experiment 6 and 7 revealed that the learned predictiveness effect was not constrained to adult humans since an orangutan and children demonstrated the same attentional bias towards predictive cues. This is important because it suggests that the contrast between human and animal performance results from differences in the methodology used to test them. Furthermore, it implies that if tested under the same conditions human and animal performance would be comparable. On the other hand, we were not able to rule out the possibility that attentional bias based on predictive validity is a uniquely hominid ability, and since orangutans share 97% of the same genes as humans perhaps it is unsurprising that they evolved similar learning mechanisms.

Chapter 4 also addressed whether the learned predictiveness effect was present on reinforced and non-reinforced trials. Previous research (see: Beesley et al., 2015; Griffiths & Mitchell, 2008; Haselgrove et al., 2015; Le Pelley et al., 2011; Le Pelley & McLaren, 2003; Le Pelley et al., 2013; Le Pelley et al., 2009; Le Pelley et al., 2010; Lochmann & Wills, 2003; Mitchell et al., 2012) used predictive contingencies during which participants were required to anticipate

which outcome, of multiple outcomes, would occur. However, in the real-world, cues are not always followed by the presence of an outcome, they are sometimes followed by the omission and it is equally important for individuals to be able to learn about these relationships too. An experimental paradigm that tries to tap into this is the allergist paradigm where the participant is required to predict whether Mr X will experience any ill effects after consuming different food combinations. For example, consuming Food 1 might result in a headache, but consuming Food 2 could be followed by nothing and is therefore safe to eat. The Mackintosh (1975) model, which is most often used to interpret the learned predictiveness effect, claims that attention will increase towards the best available predictor of *reinforcement* available on a trial. However, the model is unclear about how to deal with the role of inhibition in learning and therefore does not make any direct predictions about non-reinforced trials – although they have been assumed to function according to the same principles (see: Le Pelley, 2004).

Experiment 6 and 7 found that predictive cues on reinforced and non-reinforced trials received more attention than irrelevant cues, in children and the orangutan. This finding revealed that the learned predictiveness effect could be demonstrated on reinforced and non-reinforced trials, and consequently the Mackintosh (1975) model could be used to interpret the findings on both trial types because they were underpinned by the same underlying mechanism. To the contrary, Experiment 8, which was carried out using only adult humans, found an attentional bias towards predictive cues on reinforced trials only. However, further investigation using questionnaire data revealed that adults had only learned the predictive contingency on reinforced trials. This difference in

performance observed between adults and children or animals could result from the use of different conditioning mechanisms. It could be that visual attention in adults is more under the control of instrumental conditioning mechanisms, like that proposed by Spence (1936), who proposed differential responding to S+ and S-. According to Spence's theory, participants should have looked more towards cues that predicted reinforcement and less towards cues that predicted non-reinforcement. A possible explanation for this bias in learning rate is that it permits associative learning to be strategic and efficient. Unfortunately, eye gaze distribution could not be compared across the three participant types because there was a large variation in the number of fixations captured when testing the orangutan as she could not be instructed to attend to the screen.

In the final experimental chapter, Chapter 5 addressed a theory driven question exploring whether an attentional bias would develop between stimuli and target stimuli that were correlated with each other in the presence and absence of prediction when presented simultaneously or serially. Simultaneous conditioning studies have found that associative learning persists even in the absence of a predictive relationship between stimuli (see: Burkhart & Ayres, 1978; Heth & Rescorla, 1973; Mowrer & Aiken, 1954; Rescorla, 1980). From these results, it is clear that stimuli can be correlated and associated with each other, without being predictive. In fact, using a flavour-aversion paradigm in rats, Rescorla (1980) found that simultaneous associations were stronger than sequential associations.

Attentional models of associative learning place great emphasis on the role of predictive significance in the modulation of eye gaze during learning. For instance, the Mackintosh (1975) model uses what we have termed 'prediction

success' to drive attentional bias, and consequently future learning, whereas the Pearce-Hall (1980) model uses 'prediction error'. Despite 'prediction' being emphasised in these explanations, the formalisation of these models only allow error terms and associations to influence a cue's associative change. Thus far, it remained unknown whether prediction was necessary for learned variations in attention to be established.

The findings of Experiment 9, Group Target in Experiment 10, Group Simultaneous and Target in Experiment 11, and Stage 1 of Experiment 12, where a congruent and incongruent stimulus was presented simultaneously and serially with a target stimulus, revealed that association alone was not sufficient for the establishment of differential overt attention towards correlated and uncorrelated stimuli. This is consistent with the notion that in order for stimuli to acquire different degrees of attentional capture, they must be established as being in a *predictive* relationship with a target outcome. This conclusion is strengthened from the results of Group Cue in Experiment 10, Experiment 11, and Stage 2 of Experiment 12, where participants experienced an identical associative relationship between correlated stimuli with target stimuli, but in these conditions the relationship was *predictive* because participants were permitted to pre-empt the trial outcome.

Conversely, it was clear from the questionnaire data that participants learned the predictive contingency in all conditions in Experiments 9, 10, 11 and 12. This finding implies a dissociation between the predictive relevance of a stimulus and participants' knowledge of the associative relationship between the stimulus and target. None of the current attentional models of associative learning (e.g. Esber & Haselgrove, 2011; Kruschke, 2001; Le Pelley, 2004;

Mackintosh, 1975; Pearce & Hall, 1980; Pearce & Mackintosh, 2010) make a distinction between associative strength and prediction, and consequently would find it difficult to explain the findings of Chapter 5.

Causal models, which seek to explain the process by which people make inferences about causality between two events on the basis of their temporal relationship, are better able to accommodate the findings in Chapter 5. Causal reasoning has also been demonstrated in animals; for example, Sawa (2009) found that rats are able to generalise causal cues for food rewards. Causal models do not face the same problem as associative models when explaining the experimental findings of Chapter 5 because they make a distinction between learning and performance (see: Allan, Siegel & Tangen, 2005; Miller & Matzel, 1998). Moreover, causal models do not specify that organisms use only a single measure of the relationship (e.g. associative strength). This allows causal models to make a distinction between the different indexes people use to describe how events are related (Vadillo, Miller & Matute, 2005). A possible solution would be to integrate the distinction between learning and performance used in causal models into associative learning models. Vadillo, Miller and Matute (2005) suggested that this could be achieved by assuming that a cue → outcome association is not directly mapped onto a response. Instead, an individual might use information from associations in the process of organising a response; therefore, when people are trying to derive a causal relationship then, and only then, do they change their attention.

Together these results suggest that a predictive relationship between a stimulus and target outcome is insufficient for the establishment of an attentional bias. In order for an attentional bias to develop a stimulus needs to, firstly, be

predictive about the outcome, and secondly, have high associative strength. These results cannot be explained using attentional models of associative learning since they do not make a distinction between association and prediction. Previously, it had been assumed that contingency and spacio-temporal contiguity were necessary and sufficient to produce associations, but the experiments described in Chapter 5 suggest in order to bias attention the cue needs to provide 'information'. An alternative explanation could be that in the absence of explicit prediction, there was no prediction error signal to drive attention. Or, an attentional bias may have failed to develop because the experiment was not cognitively taxing enough. During the experiment participants were only required to press a key to indicate whether the letter Y or Z was present, therefore there was no reason to expect that overt and covert attention were tightly coupled as they are assumed to be in more cognitively taxing tasks.

During overt attention, individuals move their eyes to bring an object into sharp focus; but during covert attention, individuals attend to an object without moving their eyes. Filtering tasks (e.g. Palmer & Moore, 2009) are often used to measure covert attention, where a large number of distracters are used and the participant must identify a target. The prevailing view in the cognitive literature is that the role of covert attention is to quickly scan the visual field for areas of interest. Since the experiments in Chapter 5 used something akin to a visual search task, this might explain why no overt differences in attentional bias towards correlated and uncorrelated stimuli were observed. To address this issue, future experiments should also include a covert measure of attention such

as a dot-probe task, where the response is quicker towards the location that is being attended to.

Support for this idea was provided by studies which found that only statistical regularities that provided additional information attracted overt attention (see Alamia & Zénon, 2016), task-irrelevant statistical regularities only attracted covert attention (see: Shiu & Pashler, 1992; Ahissar & Hochstein, 1993). In Experiment 9 and Group Target in Experiment 10, Groups Target and Simultaneous in Experiment 11, and Stage 1 of Experiment 12, the correlated and uncorrelated cues were essentially task-irrelevant because even though correlated cues indicated the identity of target stimuli, the task could be accurately completed by simply responding to the target stimulus. Moreover, even if participants made a response they still had to wait for the rest of the 2,000 ms trial to pass before the next trial began. In a future experiment it would be interesting to see if no attentional bias would still be found if there was an incentive for participants to respond quickly. For example, if participants correctly identified the target stimulus in less than .3 seconds, they got a monitory bonus. However, in Group Cue of Experiment 10, Experiment 11, and Stage 2 of Experiment 12, correlated cues provided additional information because it allowed participants to anticipate the identity of the target cue before it appeared, which might explain why overt attention increased towards correlated stimuli.

6.1 Future research

6.1.1 Outcome overshadowing

Cue competition has been well documented in phenomena such as overshadowing. During an overshadowing procedure, two cues of unequal salience are presented in compound with an outcome. It has been reliably found that when tested individually, the less salient cue elicits a weaker response because it was *overshadowed* by the more salient cue during training (e.g. Jones & Haselgrove, 2011; Kamin, 1969; Mackintosh, 1971, 1976; Mackintosh & Reese, 1979; Pavlov, 1927). According to Mackintosh's (1975) model, a cue gains higher associability only if it is the best available predictor of an outcome, but this symmetry does not apply to outcomes. In contrast, recent evidence proposed by Giffiths, Mitchell, Bethmont and Lovibond (2015), and Quigley, Eatherington and Haselgrove (2017) implies that learned changes in associability can also take place for outcomes. Quigley et al. found that a previously predicted outcome was learned about better than a previously unpredicted outcome. This means that how well an outcome has been predicted in the past influences the speed at which it will enter into new associations.

In the current thesis, we also found evidence of outcome competition. For example, Experiment 1 revealed that although there was a significant difference between the amount of attention directed towards predictive and irrelevant cues, this was only present on O1 trials. On this basis, it could be argued that participants only learned one of the predictive contingencies, as this was sufficient to correctly respond on both O1 and O2 trials. However, this theory does not explain why participants consistently learned the O1

contingency, not randomly O1 or O2. This finding was supported by Experiment 8 during which adult participants only learned the cue → grape relationship, not the cue → no-grape relationship. These experiments suggest that one outcome was able to overshadow the other outcome and promote learning about that cue → outcome relationship.

To test this idea, an experiment could be designed which varied the outcome's salience using a quantifiable measure to determine whether outcome 40dB is diminished because of the 80dB (see Table 6.1). We would then compare the amount of learning about AX and BX between Groups 1 and 2, with the anticipation of poorer learning in Group 1.

Table 6.1 *Experimental design for hypothetical Experiment 1*

Group	*Compound*	*Outcome*
1	**AX**	**40dB low**
	BX	**40dB high**
	AY	**80dB low**
	BY	**80dB high**
2	**AX**	**40dB low**
	BX	**40dB high**
	AY	**40dB low**
	BY	**40dB high**

6.1.2 **Temporal separation in learned predictiveness tasks**

Existing literature has demonstrated that the greater the temporal separation between two events (cue followed by an outcome) the less likely they are to become associated with each other. Evidence for the temporal contiguity effect has been demonstrated by Renner (1964; also see: Tarpy & Sawabini,

1975; Dews, 1960, 1969; Gonzalez & Newlin, 1976 & Morgan, 1972) who found that as the delay before reinforcement increased, the rate of responding decreased. However, an exception to this rule appears to be taste aversion learning which has been found to take place with a delay of up to 12 hours between consumption and poisoning (for review, see: Domjan, 1985; Riley & Tuck, 1985a, 1985b).

A suggested reason for the temporal contiguity effect is trace decay (Brown, 1958), where the trace weakens sufficiently between the first and second time point till it is too weak for an association to be formed. This suggests that associations should be strongest when the temporal gap is smallest. However, the long temporal delay possible in taste aversion conditioning compelled Revusky (1971) to propose an alternative explanation of contiguity effects in terms of interference. The interference explanation suggested that long-delay conditioning is possible, but that the larger the temporal separation between two events, the more likely that additional events would compete for association. Taste aversion conditioning can be sustained over such long delays because nausea is most strongly associated with taste rather than, say, audio or visual events (Garcia & Koelling, 1966), but a different taste would.

To test this explanation Kwok, Livesey and Boakes (2010) carried out an experiment to determine whether the serial presentation of a flavour and outcome could overshadow taste aversion learning. They conducted a series of experiments to investigate whether events that took place before rats had access to the target taste (sucrose) could proactively interfere the acquisition of with sucrose aversion, when subsequently paired with a lithium chloride injection. Their findings revealed proactive interference by taste and novel context after

two conditioning sessions. However, overshadowing was present from the first conditioning trial if the target flavour was presented prior to the outcome, interference and proactive inference are different processes.

Despite temporal contiguity being widely accepted as influencing association formation, few models of associative learning have integrated the role of timing and prediction error (see Kirkpatrick, 2014 for a summary). Moreover, none of these models have incorporated the role of attention as specified by Mackintosh (1975). Consequently, to date, no existing literature has manipulated temporal contiguity during a learned predictiveness task. In the learned predictiveness task, stimuli are presented simultaneously in compound cues; however, in the real-world event presentation is seldom this perfect. The aim of the hypothetical experiment proposed would be to investigate whether an attentional bias could be established towards predictive cues compared to irrelevant cues when stimuli were presented serially rather than simultaneously. This would provide us with information regarding how associations are formed in the learned predictiveness effect, and its functional significance in the real-world.

Table 6.2 *Experimental design for hypothetical Experiment 2*

First cue	*Second cue*	*Outcome*	*Probe trials*
A	**X**	**O1**	**AW**
B	**X**	**O2**	**BZ**
A	**Y**	**O1**	**CX**
B	**Y**	**O2**	**DY**
C	**W**	**O1**	**AZ**
D	**W**	**O1**	**BW**
C	**Z**	**O2**	**CY**
D	**Z**	**O2**	**DX**

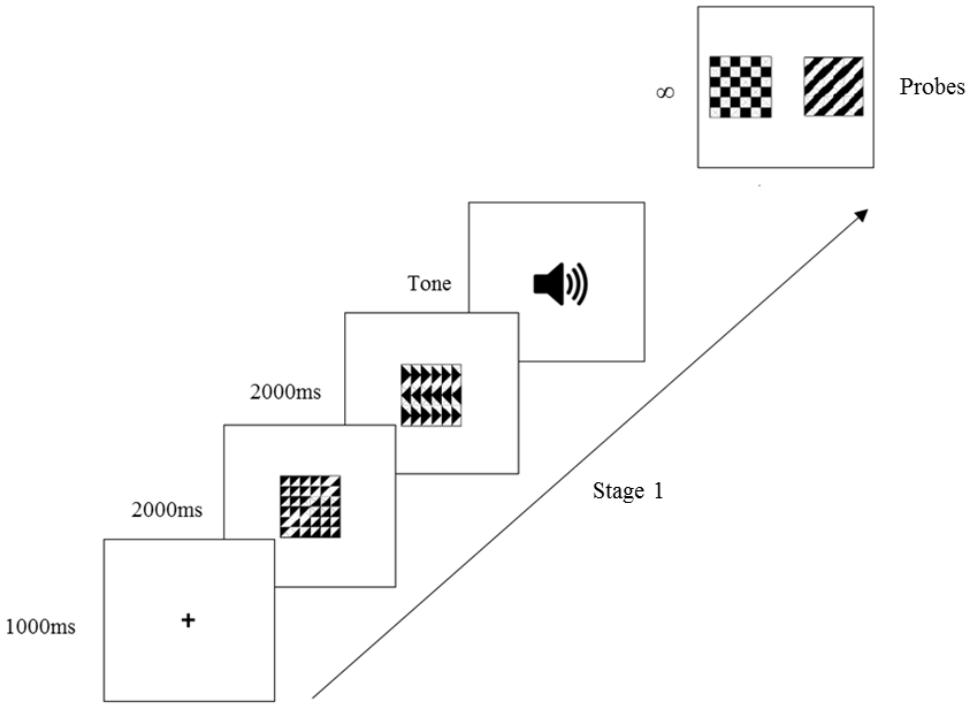


Figure 6.1 *Temporal layout of a trial during proposed Experiment 2*

6.1.3 **Learned predictiveness task in non-hominids**

Chapter 4 revealed that the learned predictiveness effect was not an ability constrained to adult humans, since an orangutan and children showed the same attentional bias towards predictive cues. This is important because it

suggests that the contrast between human and animal performance results from differences in the methodology used to test them, and that if tested under the same conditions performance would be comparable. Nevertheless, the experiments in Chapter 4 were not able to rule out the possibility that the learned predictiveness effect is a uniquely hominid ability. Credence for this argument comes from the fact that humans share 97% of the same genes as orangutans, as well as a recent evolutionary history, which is likely to have resulted in a similar mechanism for attentional allocation during associative learning.

To combat this issue, we conducted a pilot study that eye-tracked dogs during a learned predictiveness task, exploiting their position as non-hominids and frequency throughout society. Dogs were tested using the same experimental design and similar methodology used on the orangutan, children and adults in Chapter 4 (except all shapes were black). The experiment was programmed in PsychoPy, and displayed on a 50.9 × 28.6 cm monitor by a Tobii TX300. Cue compounds were presented on the screen for one second, and their offset was either followed by a clicker recording which triggered the delivery of a dog treat, or the absence of the click and consequently the absence of the treat. However, unlike Experiment 7 with children, the eye-tracker was not able to reliably detect the dog's eyes regardless of the breed or colouration. Consequently, future research would need to commission a bespoke head mounted eye-tracker like those offered by Positive Science: http://www.positivescience.com/, which was used with the orangutan.



Figure 6.2 *Inadequate experimental setup used when testing dogs*

6.1.5 **Are all irrelevant cues equally irrelevant?**

The experiments reported in this thesis have focused on what happens to different types of predictive cues (+, +/-, -) over learning, but much less research has investigated how much attention different types of irrelevant cues attract. The models of associative learning previously described make contradictory predictions with regards to the fate of irrelevant stimuli presented simultaneously with predictive stimuli. For example, the Mackintosh (1975) model suggests that unless a cue is established as the *best* predictor of reinforcement, the amount of attention it attracts will reduce. On the other hand, the Esber-Haselgrove (2011) model claims that attention towards irrelevant cues will increase over time.

In the learned predictiveness literature, the term 'irrelevant cue' simply means that it isn't needed to solve the predictive contingency; however, there are other types of irrelevant cues. For example, the redundancy effect finds greater conditioned responding towards cue X in A+/AX+ blocking training, than

towards cue Y in simple BY+/CY- discrimination training (Jones & Pearce, 2014).

Table 6.3 incorporates cues that are irrelevant for predicting O1 and O2, or irrelevant for predicting no-outcome. In future research, it would be interesting to investigate whether the amount of attention both types of irrelevant cues attracted decreased over training at the same rate during a learned predictiveness task. According to the Mackintosh (1975) model, the irrelevant cues paired with no-outcome are perfect predictors, so attention should be maintained towards these. Conversely, the Esber-Haselgrove (2011) model claims that the irrelevant cues paired with O1 and O2 should receive higher attention because they have multiple associations which would be summed.

Table 6.3 *Experimental design for hypothetical Experiment 5*

Compound	***Outcome***
AX	**O1**
BX	**O2**
AY	**O1**
BY	**O2**
CW	**--**
DW	**--**
DZ	**--**
CZ	**--**

6.2 Conclusions

Phenomena that provide support for an attentional account of associative learning have tended to find evidence for either the Mackintosh (1975) model (see: learned irrelevance, IDS/EDS, learned predictiveness effect) or Pearce-Hall (1980) model (see: superiority of partial reinforcement, Hall-Pearce negative transfer). Consequently, associative learning models with the highest explanatory power are able to accommodate enhanced processing of cues that are the best predictor of an outcome, as well as promoting attention towards cues which are uncertain predictors of an outcome (e.g. Le Pelley, 2004; Esber-Haselgrove, 2011). The aim of the current thesis was to shed light on the role of overt selective attention within associative learning, and determine which models were best able to explain the data.

Chapter 2 explored different measures of eye gaze during the learned predictiveness effect and found that dwell time, proportion of dwell time, fixation count and proportion of fixation count were all highly correlated with each other. Latency to first fixation and fixation omission were not well correlated with any measure of attention, and were therefore unlikely to tap into the same underlying mechanism. In addition, Chapter 2 also examined the influence of certainty and increased uncertainty during a learned predictiveness task and revealed that at a within-trial-level findings provided support for the Mackintosh (1975) model, but at a between-trial-level findings provided support for the Pearce-Hall (1980) model. This dichotomy between the two models has been resolved in the two models of associative learning proposed by Le Pelley (2004) and Esber and Haselgrove (2011).

Eye-tracking during learned predictiveness tasks has been thoroughly investigated (see: Beesley et al., 2015; Le Pelley et al., 2011; Le Pelley et al. 2013; Mitchell et al., 2012); however, until Chapter 3 it remained unclear whether the change in associability observed during IDS/EDS tasks was underpinned by a shift in attention. Chapter 3 revealed that participants directed more overt attention towards the dimension that was relevant for solving the discrimination and generalised this bias from Stage 1 into Stage 2. This pattern of results was not found when a degree of uncertainty was introduced into the predictive contingencies.

The existing learned predictiveness literature has exclusively tested adult human participants (for a review see Le Pelley et al., 2016). Therefore, the aim of Chapter 4 was to expand the type of participants that the learned predictiveness task has been conducted on, by establishing a simplified version of the task and back-translating the eye-tracking methodology into an orangutan and children. Chapter 4 revealed that the dichotomy between animal and human performance reflects a difference in the testing procedure or salience of the outcome, not the mechanism used to direct selective attention during associative learning.

Finally, Chapter 5 manipulated the cue → outcome relationship to explore whether an attentional bias would develop between a stimulus and a target that were correlated with each other in the presence or absence of prediction, when presented simultaneously or serially. It was revealed that in order for an attentional bias to develop a stimulus needs, firstly, to be predictive about the outcome, and secondly, to have high associative strength. These

results cannot be explained using attentional models of associative learning since they do not include a distinction between association and prediction.

6.3 Concluding comments

Attention is an important feature of several formal models of associative learning; however, it was not represented comprehensively enough to explain all the findings of the current thesis. The models proposed by Le Pelley (2004) and Esber-Haselgrove (2011) capture well the findings of Chapters 2, 3 and 4, but even they failed to specify the distinction between association and prediction revealed in Chapter 5.

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Appendix 1: Experiment 1

Version A	Version B
AV → O1	VA → O1
AW → O1	VB → O1
BV → O2	WA → O2
BW → O2	WB → O2
CX → O2	XC → O2
CY → O2	XD → O2
DX → O1	YC → O1
DY → O1	YD → O1
VA → O1	AV → O1
WA → O1	BV → O1
VB → O2	AW → O2
WB → O2	BW → O2
XC → O2	CX → O2
YC → O2	DX → O2
XD → O1	CY → O1
YD → O1	DY → O1

Appendix 2: Experiment 2

Version A	Version B	Version C	Version D
AX+	BA+	CB+	XC+
BX+/-	CA+/-	XB+/-	AC+/-
CX-	XA-	AB-	BC-
XA+	AB+	BC+	CX+
XB+/-	AC+/-	BX+/-	CA+/-
XC-	AX-	BA-	CB-

Appendix 3: Experiment 3

Version A	Version B	Version C	Version D
AV → O1	VA → O1	AV → O1(75%) O2(25%)	VA → O1(75%) O2(25%)
AW → O1	VB → O1	AW → O1(75%) O2(25%)	VB → O1(75%) O2(25%)
BV → O2	WA → O2	BV → O2(75%) O1(25%)	WA → O2(75%) O1(25%)
BW → O2	WB → O2	BW → O2(75%) O1(25%)	WB → O2(75%) O1(25%)
CX → O2(75%) O1(25%)	XC → O2(75%) O1(25%)	CX → O2	XC → O2
CY → O2(75%) O1(25%)	YD → O2(75%) O1(25%)	CY → O2	XD → O2
DX → O1(75%) O2(25%)	YC → O1(75%) O2(25%)	DX → O1	YC → O1
DY → O1(75%) O2(25%)	XD → O1(75%) O2(25%)	DY → O1	YD → O1
VA → O1	AV → O1	VA → O1(75%) O2(25%)	AV → O1(75%) O2(25%)
WA → O1	BV → O1	WA → O1(75%) O2(25%)	BV → O1(75%) O2(25%)
VB → O2	AW → O2	VB → O2(75%) O1(25%)	AW → O2(75%) O1(25%)
WB → O2	BW → O2	WB → O2(75%) O1(25%)	BW → O2(75%) O1(25%)
XC → O2(75%) O1(25%)	CX → O2(75%) O1(25%)	XC → O2	CX → O2
YC → O2(75%) O1(25%)	DX → O2(75%) O1(25%)	YC → O2	DX → O2
XD → O1(75%) O2(25%)	CY → O1(75%) O2(25%)	XD → O1	CY → O1
YD → O1(75%) O2(25%)	DY → O1(75%) O2(25%)	YD → O1	DY → O1

Version E	Version F	Version G	Version H
AV → O1	VA → O1	AV → O1(75%) O2(25%)	VA → O1(75%) O2(25%)
AW → O1	VB → O1	AW → O1(75%) O2(25%)	VB → O1(75%) O2(25%)
BV → O2	WA → O2	BV → O2(75%) O1(25%)	WA → O2(75%) O1(25%)
BW → O2	WB → O2	BW → O2(75%) O1(25%)	WB → O2(75%) O1(25%)
CX → O2(75%) O1(25%)	XC → O2(75%) O1(25%)	CX → O2	XC → O2
CY → O2(75%) O1(25%)	YD → O2(75%) O1(25%)	CY → O2	XD → O2
DX → O1(75%) O2(25%)	YC → O1(75%) O2(25%)	DX → O1	YC → O1
DY → O1(75%) O2(25%)	XD → O1(75%) O2(25%)	DY → O1	YD → O1
VA → O1	AV → O1	VA → O1(75%) O2(25%)	AV → O1(75%) O2(25%)
WA → O1	BV → O1	WA → O1(75%) O2(25%)	BV → O1(75%) O2(25%)
VB → O2	AW → O2	VB → O2(75%) O1(25%)	AW → O2(75%) O1(25%)
WB → O2	BW → O2	WB → O2(75%) O1(25%)	BW → O2(75%) O1(25%)
XC → O2(75%) O1(25%)	CX → O2(75%) O1(25%)	XC → O2	CX → O2
YC → O2(75%) O1(25%)	DX → O2(75%) O1(25%)	YC → O2	DX → O2
XD → O1(75%) O2(25%)	CY → O1(75%) O2(25%)	XD → O1	CY → O1
YD → O1(75%) O2(25%)	DY → O1(75%) O2(25%)	YD → O1	DY → O1

Appendix 4: Experiment 4

	Version A	Version B	Version C	Version D	Version E	Version F
Stage 1	AX → O1	AX → O1	AX → O1	AX → O1	AX → O1	AX → O1
	BX → O2	BX → O1	BX → O2	BX → O1	BX → O2	BX → O1
	AY → O1	AY → O2	AY → O1	AY → O2	AY → O1	AY → O2
	BY → O2	BY → O2	BY → O2	BY → O2	BY → O2	BY → O2
	XA → O1	XA → O1	XA → O1	XA → O1	XA→ O1	XA → O1
	XB → O2	XB → O1	XB → O2	XB → O1	XB → O2	XB → O1
	YA → O1	YA → O2	YA → O1	YA → O2	YA → O1	YA → O2
	YB → O2	YB → O2	YB → O2	YB → O2	YB → O2	YB → O2
Stage 2	CW → O1	CW → O1	CW → O1	CW → O1	CW → O1	CW → O1
	DW → O2	DW → O1	DW → O2	DW → O1	DW → O2	DW → O1
	CV → O1	CV → O2	CV → O1	CV → O2	CV → O1	CV → O2
	DV → O2	DV → O2	DV → O2	DV → O2	DV → O2	DV → O2
	WC → O1	WC → O1	WC → O1	WC → O1	WC → O1	WC → O1
	WD → O2	WD → O1	WD → O2	WD → O1	WD → O2	WD → O1
	VC → O1	VC → O2	VC → O1	VC → O2	VC → O1	VC → O2
	VD → O2	VD → O2	VD → O2	VD → O2	VD → O2	VD → O2

Appendix 5: Experiment 5

	Version A	Version B	Version C	Version D	Version E
Stage 1	AV → J	VA → J	VA → J	AV → J	AV → J(75%) D(25%)
	BV → D	VB → J	VB → J	BV → D	BV → D(75%) J(25%)
	AW → J	WA → D	WA → D	AW → J	AW → J(75%) D(25%)
	BW → D	WB → D	WB → D	BW → D	BW → D(75%) J(25%)
	VA → J	AV → J	AV → J	VA → J	VA → J(75%) D(25%)
	VB → D	BV → J	BV → J	VB → D	VB → D(75%) J(25%)
	WA → J	AW → D	AW → D	WA → J	WA → J(75%) D(25%)
	WB → D	BW → D	BW → D	WB → D	WB → D(75%) J(25%)
Stage 2	AV → Y	AV → Y	VA → B	VA → B	AV → Y(75%) B(25%)
	BV → B	BV → B	VB → B	VB → B	BV → B(75%) Y(25%)
	AW → Y	AW → Y	WA → Y	WA → Y	AW → Y(75%) B(25%)
	BW → B	BW → B	WB → Y	WB → Y	BW → B(75%) Y(25%)
	VA → Y	VA → Y	AV → B	AV → B	VA → Y(75%) B(25%)
	VB → B	VB → B	BV → B	BV → B	VB → B(75%) Y(25%)
	WA → Y	WA → Y	AW → Y	AW → Y	WA → Y(75%) B(25%)
	WB → B	WB → B	BW → Y	BW → Y	WB → B(75%) Y(25%)

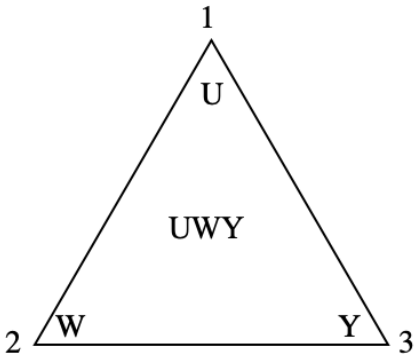
	Version F	Version G	Version H
Stage 1	VA → J(75%) D(25%)	VA → J(75%) D(25%)	AV → J(75%) D(25%)
	VB → J(75%) D(25%)	VB → J(75%) D(25%)	BV → D(75%) J(25%)
	WA → D(75%) J(25%)	WA → D(75%) J(25%)	AW → J(75%) D(25%)
	WB → D(75%) J(25%)	WB → D(75%) J(25%)	BW → D(75%) J(25%)
	AV → J(75%) D(25%)	AV → J(75%) D(25%)	VA → J(75%) D(25%)
	BV → J(75%) D(25%)	BV → J(75%) D(25%)	VB → D(75%) J(25%)
	AW → D(75%) J(25%)	AW → D(75%) J(25%)	WA → J(75%) D(25%)
	BW → D(75%) J(25%)	BW → D(75%) J(25%)	WB → D(75%) J(25%)
Stage 2	AV → Y(75%) B(25%)	VA → Y(75%) B(25%)	VA → B(75%) Y(25%)
	BV → B(75%) Y(25%)	VB → B(75%) Y(25%)	VB → B(75%) Y(25%)
	AW → Y(75%) B(25%)	WA → Y(75%) B(25%)	WA → Y(75%) B(25%)
	BW → B(75%) Y(25%)	WB → B(75%) Y(25%)	WB → Y(75%) B(25%)
	VA → Y(75%) B(25%)	AV → Y(75%) B(25%)	AV → B(75%) Y(25%)
	VB → B(75%) Y(25%)	BV → B(75%) Y(25%)	BV → B(75%) Y(25%)
	WA → Y(75%) B(25%)	AW → Y(75%) B(25%)	AW → Y(75%) B(25%)
	WB → B(75%) Y(25%)	BW → B(75%) Y(25%)	BW → Y(75%) B(25%)

Appendix 6: Experiment 7 and 8

Version A	Version B	Version C	Version D
AX-	AX+	AX+	AX-
BX+	BX-	BX+	BX-
AY-	AY+	AY-	AY+
BY+	BY-	BY-	BY+

Appendix 7: Experiment 9

Version	Target	Relevant	Irrelevant
A	U V	Y Z	W or X
B	U V	W X	Y or Z
C	W X	Y Z	U or V
D	W X	U V	Y or Z
E	Y Z	W X	U or V
F	Y Z	U V	W or X



	Version A	Version B	Version C	Version D	Version E	Version F
Normal	UWY	UYW	WUY	WYU	YUW	YWU
trials	UYW	UWY	WYU	WUY	YWU	YUW
	WUY	YUW	UWY	YUW	UYW	WYU
	WYU	YWU	VWY	YWU	UWY	WUY
	YWU	WYU	UYW	UYW	WYU	UWY
	YUW	WUY	YUW	UWY	WUY	UYW
	VXZ	VZX	YWU	UWZ	ZVX	ZXV
	VZX	VXZ	XVZ	XZV	ZXV	ZVX
	XVZ	ZVX	XZV	XVZ	VZX	XZV
	XZV	ZXV	VYZ	ZVX	VXZ	XVZ
	ZXV	XZV	VZX	ZXV	XZV	VZX
	ZVX	XVZ	ZVX	VZY	XVZ	VXZ
	UXY	UZW	ZXV	VXZ	YVW	YXU
	UYX	UWZ	WVY	WZU	YWV	YUX
	XUY	ZUW	WYV	WUZ	VYW	XYU
	XYU	ZWU	VYW	ZUW	VWY	XUY
	YXU	WZU	YVW	ZWU	WYV	UXY
	YUX	WUZ	YWV	UWZ	WVY	UYX
	VWX	VYX	XUZ	XYV	ZUX	ZWV
	VZW	VXY	XZU	XVY	ZXU	ZVW
	WVZ	YVX	UXZ	YVX	UZX	WZV
	WZV	YXV	UZX	YXV	UXZ	WVZ
	ZWV	XYV	ZUX	VYX	XZU	VZW
	ZVW	XVY	ZXU	VXY	XUZ	VWZ

No target trials	YWO	WYO	YUO	UYO	WUO	UWO
	OYW	OWY	OYU	OUY	OWU	OUW
	WOY	YOW	UOY	YOU	UOW	WOU
	WYO	YWO	UYO	YUO	UWO	WUO
	OWY	OYW	OUY	OYU	OUW	OWU
	YOW	WOY	YOU	UOY	WOU	UOW
	YXO	WZO	YVO	UZO	WVO	UXO
	OYX	OWZ	OYV	OUZ	OWV	OUX
	XOY	ZOW	VOY	ZOU	VOW	XOU
	XYO	ZWO	VYO	ZUO	VWO	XUO
	OXY	OZW	OVY	OZU	OVW	OXU
	YOX	WOZ	YOV	UOZ	WOV	UOX
	ZWO	XYO	ZUO	VYO	XUO	VWO
	OZW	OXY	OZU	OVY	OXU	OVW
	WOZ	YOX	UOZ	YOV	UOX	WOV
	WZO	YXO	UZO	YVO	UXO	WVO
	OWZ	OYX	OUZ	OYV	OUX	OWV
	ZOW	XOY	ZOU	VOY	XOU	VOW
	ZXO	XZO	ZVO	VZO	XVO	VXO
	OZX	OXZ	OZV	OVZ	OXV	OVX
	XOZ	ZOX	VOZ	ZOV	VOX	XOV
	XZO	ZXO	VZO	ZVO	VXO	XVO
	OXZ	OZX	OVZ	OZV	OVX	OXV
	ZOX	XOZ	ZOV	VOZ	XOV	VOX

Appendix 8: Experiment 10 (expanded counterbalancing the same as Experiment 9)

Version	Condition	Target	Relevant	Irrelevant
A	Simultaneous	Q P	B X	G or Y
B	Simultaneous	Q P	G Y	B or X
C	Simultaneous	Q P	J V	W or Z
D	Simultaneous	Q P	W Z	J or V
E	Serial	Q P	J V	W or Z
F	Serial	Q P	W Z	J or V
G	Serial	Q P	B X	G or Y
H	Serial	Q P	G Y	B or X

Probes
BGO
OBY
XOG
XYO
OJW
JOZ
VWO
OVZ
GOB
YBO
OGX
YOX
WJO
OZJ
WOV
ZVO

O = blank space

Appendix 9: Experiment 11 (expanded counterbalancing the same as Experiment 9)

Version	Condition	Shift	Stage	Relevant	Irrelevant	Target
A	Simultaneous congruent	Congruent	1	A B	X Y	P or Q
A	Simultaneous incongruent	Incongruent	1	A B	X Y	P or Q
A	Serial congruent	Congruent	1	A B	X Y	P or Q
A	Serial incongruent	Incongruent	1	A B	X Y	P or Q
B	Simultaneous congruent	Congruent	1	X Y	A B	P or Q
B	Simultaneous incongruent	Incongruent	1	X Y	A B	P or Q
B	Serial congruent	Congruent	1	X Y	A B	P or Q
B	Serial incongruent	Incongruent	1	X Y	A B	P or Q

Version	Condition	Shift	Stage	Relevant	Irrelevant	Target
A	Simultaneous congruent	Congruent	2	A B	X Y	P or Q
A	Simultaneous incongruent	Incongruent	2	X Y	A B	P or Q
A	Serial congruent	Congruent	2	A B	X Y	P or Q
A	Serial incongruent	Incongruent	2	X Y	A B	P or Q
B	Simultaneous congruent	Congruent	2	X Y	A B	P or Q
B	Simultaneous incongruent	Incongruent	2	A B	X Y	P or Q
B	Serial congruent	Congruent	2	X Y	A B	P or Q
B	Serial incongruent	Incongruent	2	A B	X Y	P or Q

Letters:
A = J
B = V
X = W
Y =Z