Stimulus property effects on cue competition and temporal estimates during causal learning

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Abstract

      Learning and timing models have developed along different trajectories within psychology; however, more recent theorising has speculated that both of these phenomena might be modelled within a single theoretical model. While such an approach has merit, the majority of studies into how learning and timing interact have employed nonhuman subjects. Consequently, little is known about how these core psychological processes might interact in humans; this body of experiments was, conducted in order to investigate this issue. Experiments were run to test the hypothesis that cue competition attenuates the ability of participants to estimate a stimulus' temporal parameters. By studying whether temporal estimates differed between cues in conditions in which blocking and overshadowing was predicted to be weaker or stronger, it could be determined whether time and association were encoded together. In a series of causal learning experiments participants were trained with a cue competition paradigm. On test both cue competition and temporal estimates were examined. The results showed that participant instructions influenced cue competition and that cue properties could influence blocking and overshadowing in specific cases. Temporal estimates made by participants were influenced by cue properties: less accurate estimates of target cue duration were made in several experiments, and temporal estimates between groups varied when blocking and overshadowing were constant. Existing associative learning theories could predict blocking and overshadowing, but could not predict the temporal results. Timing models, for example, the SET model, failed to predict temporal results. To conclude, the results suggest that timing is not encoded as part of the association.

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Chapter 1. Introduction

Learning is defined by Pearce (1997) as a change in behaviour that is long-lasting, is the result of previous experience, and is important for animals and humans. Learning is advantageous as animals (Shettleworth, 2001) that are able to learn where to source food and which dangers to avoid have an advantage to animals that do not manage to learn. Thus the ability to detect correlations between events has a survival value (Pearce, 1997). The experimental study of this phenomenon assumes that learning has taken place by looking at changes in the strength of a subjects' response. A response is a (learned) behaviour that occurs when a stimulus that is paired with an outcome is encountered in the experimental context (Schwartz & Robbins, 1995). In an experimental setup, a response to a known stimulus can be compared to the reaction or response elicited by a novel stimulus to see if there is a discrepancy between the two; if there is a discrepancy it can be assumed that the subject has learned about the stimulus (Rescorla & Wagner, 1972).

Several learning mechanisms can be identified: habituation, operant (or instrumental) conditioning and Pavlovian, also known as classical, conditioning (Schwartz & Robbins, 1995). Habituation is when a participant stops responding to a stimulus because it has been exposed to a stimulus repeatedly (Shanks, Preston, & Stanhope, 1986). A type of Pavlovian conditioning is inhibition. This is when a subject is trained to stop responding to a stimulus, thus, this is when the response or behaviour has actively been suppressed (Lotz, Vervliet, & Lachnit, 2009; Rescorla, 1969). Inhibition is often seen as an active process, whilst habituation is passive. Operant (or instrumental) conditioning is when an experimenter delivers an event after a subject has shown a particular behaviour (Pearce, 1997), or in other words, a behavioural response pattern is rewarded. After an animal has learned to show a particular behaviour when a stimulus is shown, it may exhibit that behaviour pattern when similar stimuli are encountered.

Classical and operant conditioning seem similar; however, in Pavlovian conditioning the participant associates a predictive or conditioned stimulus (CS) with a contingent event or unconditioned stimulus (US) (Savastano & Miller, 1998). In operant conditioning an expressed behaviour is associated with its outcome, or in other words, there is a contingency between the response and the reinforcer (Dickinson & Balleine, 1994). However, the mechanism for both the conditioning types might be similar

(Lorenzetti, Mozzachiodi, Baxter, & Byrne, 2006), though Lorenzetti et al. (2006) found an increase in the input resistance in operant conditioning but did not find this for classical conditioning. The Pavlovian to Instrumental transfer (PIT) effect is used to test a possible interaction between operant and Pavlovian conditioning due to differences in motivation between the two types of learning (Dickinson & Balleine, 1994).

1.1   Classical (Pavlovian) Conditioning

Pavlovian conditioning is the process whereby two events are paired. Unlike during operant conditioning, a reward is presented when a stimulus has been shown during Pavlovian conditioning, irrespective of whether or not the subject has elicited behaviour (Pearce, 1997). For example, in a simple delay procedure, the first event is initially a neutral stimulus while the second event with which it is paired is usually of biological significance to the subject (e.g. food), and the two events co terminate (Cheng, Disterhoft, Power, Ellis, & Desmond, 2008). Following a certain number of pairings between these events, presentation of the neutral event comes to elicit responding when it is presented. In other words, classical conditioning occurs when (an initially neutral) CS is paired as a signal for the unconditioned stimulus (US) which in turn gives rise to an unconditioned response (UR). After training, the CS will give rise to a UR, even when the US is no longer present and it first was necessary to elicit the UR (C. Mitchell, De Houwer, & Lovibond, 2009; Rescorla, 1988). The contingency between CS and US is important in Pavlovian conditioning (Dickinson, Shanks, & Evenden, 1984; Wasserman, Elek, Chatlosh, & Baker, 1993).

There are different types of Pavlovian conditioning; simultaneous conditioning is when CS and US presentation starts and ends at the same time, backward conditioning is when the CS is presented immediately following the termination of the US, delay conditioning is when the shorter US is presented at the end of the CS and they both terminate at the same time, and trace conditioning is when the US starts after termination of CS. Varying results have been found when examining the success of the different conditioning types (Barnet, Arnold, & Miller, 1991; Chang, Blaisdell, & Miller, 2003; Kattner, Ellermeier, & Tavakoli, 2012; Rescorla, 1980).

1.2   Association formation during Pavlovian conditioning

The present experimental series concentrate on the mechanism of Pavlovian conditioning by which we can study how associations are formed, namely associative

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learning. The ability to form associations between events is a basic form of learning that humans and other animals share (Dickinson et al., 1984; Vanhamme & Wasserman, 1994). This is when a subject learns the relationship between two events and an association between two stimuli (such as a cue and its outcome) is formed. The key aspect of this type of learning is that one event is usually neutral with respect to the outcome and through experience or repeated pairings of the stimulus and the outcome, an association is formed between the two, even when at first the two stimuli do not necessarily have any obvious connection. One event will almost always be a biologically motivational event which will facilitate the formation of the association (Wasserman & Miller, 1997).

An associative learning task consists of several steps; one event (the conditioned stimulus, CS) is paired with a second event (the unconditioned stimulus, US) which eventually gives rise to a conditioned response (CR) (Pearce & Bouton, 2001; Rescorla & Wagner, 1972). Therefore, an association forms between the CS and US (Pearce & Bouton, 2001; Rescorla, 1988; Rescorla & Wagner, 1972).

1.2.1 Overshadowing

Cue competition occurs when two or more cues or stimuli are presented in compound leading to the assumption that all events that predict the outcome compete with each other for associative strength (Vandorpe, de Houwer, & Beckers, 2007). Cue competition shows that the contingency between the CS and US is not predictive of learning, as experiments have shown that temporal contiguity between a CS and US does not necessarily lead to learning (Kamin, 1969; Rescorla, 1968). Experiments have shown that the information the CS supplies (or its predictability) about the US is most important in learning (Kamin, 1969; Rescorla, 1968), not contiguity.

In a typical overshadowing paradigm, a training phase consists of presentation of two stimuli (for example CS1 and CS2) in compound paired with a US (+) (Jennings, Bonardi, & Kirkpatrick, 2007; Pavlov, 1927; Pearce, Graham, Good, Jones, & McGregor, 2006; Urushihara & Miller, 2007; Wheeler & Miller, 2007). In this training phase, a single stimulus (for example, E) is also presented individually, reinforced with a US (+). After the training phase, responses are measured for every stimulus separately in a test phase. Responding to the two stimuli which were presented in compound in the training phase (CS1 and CS2) will be attenuated compared to the response to the single stimulus (E), see Figure 1.1 for response rates.

1.2.2   *Blocking*

Kamin (1969) reported a series of experiments that demonstrated that pre-training a stimulus resulted in less responding to a stimulus subsequently placed in compound with it – an effect he called blocking. Kamin looked at the attention animals paid to cues, and whether different types of conditioning would influence associative strength. Kamin used a conditioned suppression task in rats to design a blocking paradigm, and also tested a control group. In the test group, prior to the suppression task, rats were trained to press a bar to get food when they heard the noise (CS1). Then, in the first training phase, he presented rats with CS1 and a shock (US). The US would overlap the CS1 for 0.5 s and they would co-terminate. The US would cause the rat to stop bar pressing. When the animals had learned not to press the bar when hearing CS1, they would enter a second training phase. In the second phase rats were presented with a compound of two cues, CS1 (the noise) and a second novel stimulus, CS2 (a light). The compound stimulus was followed by the presentation of the shock-US; this would also train them to stop bar pressing. After the second phase, Kamin tested the response to CS2 and whether or not the light would suppress the bar pressing. He found that CS2 did not suppress the rats' behaviour to press the bar. Therefore, previous conditioning of CS1 had blocked conditioning to a new stimulus, CS2. In the control group Kamin did not present rats with any cues in phase one. Then, in the second phase he presented subjects with CS1 in compound with CS2. After the control group completed the second phase, responses were tested for CS1 and CS2. He found that in the control group, levels of responding were similar for CS1 and CS2, and this blocking no longer was observed.

Blocking has been shown over a wide variety of experimental setups (see Chapter 2.1, Table 1), thus demonstrating its generality and importance as a means by which learning can be studied (Hinchy, Lovibond, & Terhorst, 1995; Kehoe, Schreurs, & Amodei, 1981; Kruschke & Blair, 2000; Le Pelley, Oakeshott, & McLaren, 2005).When subjects are presented with CS1 in an initial phase, and then with CS1 and CS2 in compound in a second phase, responding to CS2 will always be attenuated, see Figure 1.1. The experimental setup causes the associative strength for the first stimulus that is presented to be stronger than the stimulus that is presented second and in compound (Shanks, 2007).
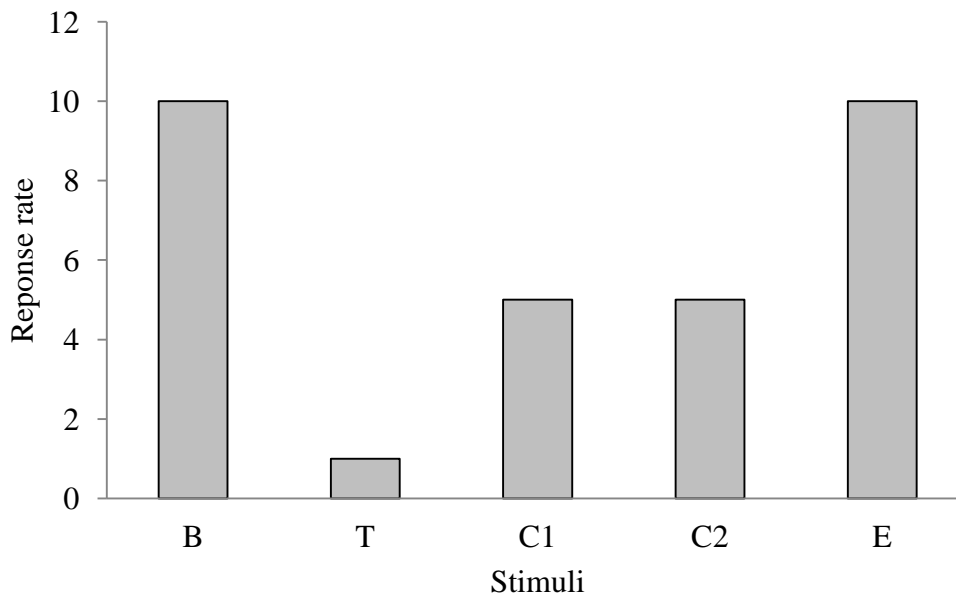
Figure 1.1. Predicted response rates for different stimuli to test blocking and overshadowing. B is the blocking stimulus, T the target stimulus, C1 and C2 compound control stimuli and E the overshadowing control.

After Kamin had successfully shown blocking, studies looked at whether blocking could also be found in humans, as similar mechanisms might be responsible for learning in humans and non-human animals (Arcediano & Matute, 1997; Le Pelley, Oakeshott, & McLaren, 2005; Mitchell et al., 2009). Dickinson, Shanks and Evenden (1984) were one of the first to study cue competition and blocking in humans. They found that theories explaining animal conditioning could also be used to explain human conditioning. Le Pelley, Oakeshott, Wills & McLaren (2005) also looked at whether animals and humans use the same learning mechanism in conditioning and blocking. Both previous studies suggest that animals and humans have common underlying associative mechanisms.

Most of the previously mentioned studies are about forward blocking (De Houwer & Beckers, 2003; Dickinson et al., 1984; Le Pelley, Oakeshott, & McLaren, 2005). Forward blocking is when a single CS (stimulus) signals US onset in the first training phase, and in the second phase, two cues presented in compound signal US onset. Backward blocking, which can help explore cue competition in different ways, can also be tested. Backward blocking is when the subject has to look back at the information that it has gathered during its training (Aitken & Dickinson, 2005); i.e. the phases are reversed; in the first training phase two cues presented in compound signal the US onset, and in the second training phase a single CS signals the US (Gallistel &

Gibbon, 2000). For example, backward blocking can test when an association is made, and to see if an established association can be altered afterwards (Shanks, 1985) and to see if this is similar in humans and non-human animals (Miller & Matute, 1996). Some studies report that backward blocking is not possible in animals but is possible in humans (Urcelay, Perelmuter, & Miller, 2008; Wasserman & Miller, 1997), also some studies indicate that backward blocking is not as strong as forward blocking (Chapman, 1991). Thus, in the experiments in this thesis a forward blocking experimental setup was tested.

The associative learning studies use different theories and models to explain cue competition (blocking and overshadowing). Some concentrate on associative learning theories, some look at timing models and some (try) to combine both. There are approximately four general models of learning. In the next section examples of older and newer models and how they work will be brought forward. This will hopefully give a clear understanding as to which model is most appropriate to study learning mechanisms in humans.

1.3   Models of association formation

Early associative learning models, for example that forwarded by Bush and Mosteller (1951), assumes that when two events (CS and US) are close in temporal contiguity, an association is formed between the CS and the US, and when CS is shown, the representation of the other would be retrieved as well (Arcediano, Escobar, & Miller, 2004). This model predicts that all cues which are presented in contiguity with a US will form an association (Bush & Mosteller, 1951). This means it does support certain cue competition paradigms, such as overshadowing because in overshadowing all cues are presented in the same phase and cues still elicit a response, even though it is a weaker response if a cue is overshadowed. However, it does not support blocking, as after training with a blocking paradigm (even when cues are presented contiguously), the blocking cue will elicit a response, whilst a second target cue will not (Kamin, 1969). Thus, the key failure of this model is that it cannot explain blocking, therefore, a new approach was needed that could explain cue competition.

According to the Rescorla -Wagner model (1972) (hereafter referred to as RW model), learning is mediated by the 'surprisingness' of the outcome and occurs on a negatively accelerating curve (Schwartz & Robbins, 1995). During the first few trials the model predicts that conditioning strength increases rapidly but, as the number of

trials increases, and the subject encounters the stimulus (CS) and the accompanying outcome (US) more often, the conditioning strength increases less rapidly because subjects have less to learn, and thus, learning increases less rapidly (Rescorla & Wagner, 1972). Eventually, the subject knows the CS predicts the US and there is no surprise. Learning stops occurring and has reached an asymptote; this is when the association between the CS and US is the strongest possible.

  The RW model (1972) was developed to be able to predict the strength of the CR when the contingency between the CS and US failed to show the expected CR (e.g. blocking). Rescorla and Wagner's model also limits the increase in associative strength that is possible but was innovative because it states that the prediction of the US on a trial depends not on a single CS but on all the CSs that are present on that trial, therefore conditioned responding depends on the current associative strength of all stimuli present on that trial (Wasserman & Miller, 1997). These characteristics enable cue competition to be explained (Le Pelley, Oakeshott, & McLaren, 2005; Miller & Shettleworth, 2007).

  To calculate the change in associative strength for stimulus A on a conditioning trial the following formula (Rescorla & Wagner, 1972) is used:

$$\Delta V_A = \alpha\beta \ (\lambda - V_T)$$

The change in associative strength for a stimulus A is ΔV_A which is influenced by α which is determined by the salience of the CS and β which takes into account the characteristics of the reinforcer (Pearce & Hall, 1980). The change in associative strength also depends on the difference in the strengths of all stimuli present on the trial (V_T) and the asymptote (λ) (Pearce & Bouton, 2001; Rescorla & Wagner, 1972). The asymptote is the greatest amount of learning or associative strength that the US can support. When two stimuli are presented in compound, the associative strength of the compound, V_{AX}, must be specified in terms of the strengths of the components. The assumption is that: $V_{AX} = V_A + V_X$.

  The RW model is a US processing model, as the model states that there is limited reinforcer (US) processing (Rescorla & Wagner, 1972) and learning depends on reinforcement. In a standard blocking paradigm, CS1 will be followed by a US. Over learning trials, the subjects will learn CS1 is followed by a US. In the second phase, CS1 is presented in compound with CS2. However, when subjects see the CS1, they already know which US corresponds with this outcome, and thus they do not learn about CS2. Hence, according to the RW model, blocking is the result of a failure of the target cue to acquire associative strength (Wasserman & Castro, 2005).

The Mackintosh model (1975b) takes a different approach from the RW model (1972), emphasising that learning is based on selective attention. Mackintosh argued that the amount of attention that will be paid to a stimulus (CS) depends on how well it predicts a US (Bouton, 2007). The better the CS is at predicting a US, the more attention a subject will pay to it and the greater the associative strength (Pearce & Hall, 1980). For the USs that receive less attention, the associative strength will decrease (Le Pelley & McLaren, 2003). The model uses the inverse hypothesis which states that; 'as attention to relevant stimuli increases, so attention to irrelevant stimuli must decrease' (page 280, Mackintosh, 1975b).

Mackintosh (1975) predicted that the associative strength changes due to experience. The model states that the associative strength of a stimulus changes on each trial. Therefore, associative strength of that cue that best predicts the outcome will increase and the other associative strengths for the other cues will decrease (Mackintosh, 1975b; Wasserman & Miller, 1997). During a trial the respective changes have no influence on learning; it is only after completion of the trial that the associative strength changes 'take effect' (Mackintosh, 1975b; Wasserman & Miller, 1997).

The Mackintosh model is a CS processing model; Mackintosh predicted that there is limited stimulus (CS) processing (Mackintosh, 1975b). As a result, when two stimuli are presented in one trial, there is limited attention available to process both CSs simultaneously. So after conditioning, one of the associations between the stimuli will be stronger than the other (Mackintosh, 1978). Thus, it can explain blocking.

Pearce and Hall (1980) proposed that learning proceeded in a different manner than that proposed in Mackintosh's attentional model (1975b). They assumed that subjects pay attention to stimuli that are novel or of which it is not yet known what they predict (Pearce & Bouton, 2001; Pearce & Hall, 1980). They proposed that it is important for subjects to pay attention to a stimulus while they are learning about its significance but that learning will eventually reach a stable asymptote which once reached will reduce the subjects' attention to that stimulus in favour of other events. As with the RW model (Rescorla & Wagner, 1972), the associative strength of a stimulus will be high when it is followed by a US that is unexpected, and the associability (and strength of conditioned response) will be low for a stimulus when it is followed by a US that is expected (Pearce & Bouton, 2001). Therefore, during conditioning associative strength will increase and reach asymptote due to repeated pairing of a CS and a US (Hall & Rodriguez, 2011).

The Pearce and Hall (1980) model is also a CS processing model. However, in contrast to Mackintosh's model (1975b), Pearce and Hall suggested that stimuli that predict the outcomes, i.e. that are not at all surprising, will not receive any processing. However, stimuli that are followed by surprising or unexpected outcomes will be processed. Pearce and Hall expected that when an animal experiences an 'appropriate' CS and US closely one after the other, the processing of them both results in the strengthening of the association between their internal representations. They anticipated that the associative strength of a cue depends on how surprising the outcome (US) was according to the previously presented cue (CS) (Pearce & Hall, 1980; Wasserman & Miller, 1997).

The Pearce Hall model (1980) can explain blocking because the model predicts that the associative strength between CS1 and US will rise to asymptote during the first phase of learning. In the second training phase, the associability for CS2 is high on the first trial, and CS2 acquires strength. However, the presence of CS1 with US means that the associability of CS2 falls to zero as a result, because the US is already fully predicted by CS1 and no longer surprising. Thus, no further acquisition occurs, and CS2 is blocked (Pearce & Hall, 1980).

However, there are shortcomings to the models mentioned above; the models fail to predict certain cue competition phenomena (Dickinson, Nicholas, & Mackintosh, 1983; Mackintosh & Reese, 1979; Wasserman & Berglan, 1998). For example, the RW model cannot predict a reduction in associative strength for new cues or cues that were presented in previous trials, as it predicts that learning about a cue requires it to be present in the trial (Wasserman & Berglan, 1998). The Mackintosh model (Mackintosh, 1975b) and the Pearce Hall model (Pearce & Hall, 1980) cannot explain single trial overshadowing (Mackintosh & Reese, 1979) or single trial blocking (Dickinson et al., 1983), which is when blocking and overshadowing are observed after one trial. Also, none of the above models can account for timing.

Wagner (1981) proposed a very different model; a real time model named the Sometimes Opponent Process or Standard Operating Procedure in which stimuli are represented by nodes. Each node is composed of a number of elements. These elements can have different activation states; the elements can either be in activation state A1 or A2 or in an inactivation state (I). A proportion of elements can be activated from inactive (I) to A1, active. Then, after a while, the elements 'decay' to state A2, and then finally back to I. When a node is activated by an associative connection, the A1 stage is

bypassed, and the state of the element goes straight from I to A2. This property allows SOP to predict learning effects (Aitken & Dickinson, 2005).

The SOP can also explain blocking. During the first training phase, when a single CS1 is shown, the outcome elements of this cue are activated into A2 prior to the US presentation (Aitken & Dickinson, 2005). Thus, in the second training phase when cue CS1 and CS2 are presented in compound with the US, fewer elements of the US are available for activation from I state to A1 state (Aitken & Dickinson, 2005). As a result, the reduced number of US elements concurrently in A1 with CS2 elements attenuates the amount of excitatory learning to CS2 (Aitken & Dickinson, 2005). Also, the experimental setup causes CS2 elements to be in A1 state, whilst US elements are in A2. The US elements are in state A2 as the presentation of CS1 caused them to be driven from I directly to A2. In SOP, simultaneous activation of cue elements in A1 and US elements in A2 leads to the inhibitory association between CS and US nodes to be strengthened (Wagner, 1981).

There have been attempts to explain how timing and associative learning work within the SOP model (Vogel, Brandon, & Wagner, 2003). Vogel et al. (2003) added assumptions to the existing SOP model (Wagner, 1981), namely; that two types of elements represent the CS. The first type are temporally distributed elements that are responsible for temporal discrimination, and the second type are randomly distributed elements, that are responsible for overall conditioning (Vogel et al., 2003). However, the SOP extension predicts that only one mechanism will operate at the same time; when stimuli are presented randomly, the random elements will be active, and when stimuli are at regular intervals, temporal elements will be active (Vogel et al., 2003). Therefore, when CSs and USs are presented at certain intervals, timing will be possible with SOP, however, if they are presented at random intervals it will not.

However, the SOP model cannot deal with retrospective revaluation (e.g. backward blocking) (Aitken & Dickinson, 2005). For example, in phase 1, the blocking and target cue are presented in compound with the outcome. As they are presented in compound, the SOP predicts that these cues and the outcome enter into A2 state. In phase 2, the blocking cue is presented with the outcome, and enters into A1 state. However, the target cue is in A2 state, which means there can be no revaluation (or learning) of the target cue and blocking does not occur as the target cue is still associated with the outcome. Thus, the SOP also has limitations.

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1.4   The role of temporal factors in learning

Timing is the ability to estimate the time of an event, and like learning is a core psychological process. Pavlov (1927) suggested that time and associative strength were central to learning as timing can influence the response of a subject on a stimulus. He believed that if a CS had a long duration that the initial portion of the CS would develop inhibitory properties – an effect he termed inhibition of delay (Pavlov 1927). However, for the most part, timing models have evolved separately from conditioning models to explain timing. However, timing experiments use similar methods to learning experiments (Kirkpatrick & Church, 1998). Timing models make predictions about how time is processed stressing the importance of when and if a subject chooses to respond (Kirkpatrick & Church, 1998). Conditioning models also predict if a subject will respond, but concentrate more on the associative strength between stimuli to make this prediction (Kirkpatrick & Church, 1998).

One of the most important models is the Scalar Timing Model or Scalar Expectancy Theory (SET) (Gibbon, 1977, 1991; Gibbon & Balsam, 1981) which predicts that patterns of responding in time rely on relative units of time (proportion of intervals as timed by subject), not absolute units of time (such as seconds) (Church, 2003). The SET model is also known as an information-processing model of timing as it states that subjects process temporal information to decide if and when to respond to cues. It assumes there are three aspects to accurate timing; the first is an internal clock or pacemaker which measures the amount of time that has passed from a certain point (Gibbon, 1991). The second aspect is a 'reference memory' or a 'memory storage mechanism' which records an important time point that might need to be remembered at a later point in time. Lastly, there is a comparator process which looks at the current time and compares that to a time point that has been 'saved' for reference (Gibbon, 1991). So the three parts (see Figure 1.2) are responsible for timing, storage and responding respectively (Allan, 1998).

```
        ┌─────────────┐
        │ Start signal│
        └─────────────┘
               │
               ▼
┌──────────────────────┐       ┌──────────────────┐
│        Clock         │──────▶│  Reference memory │
│ (Pacemaker/Accumulator)│     └──────────────────┘
└──────────────────────┘
               ╲                    ╱
                ╲                  ╱
                 ◆──────────────◆
                 │  Comparator  │
                 ◆──────────────◆
                       │
                       ▼
                   Response
```
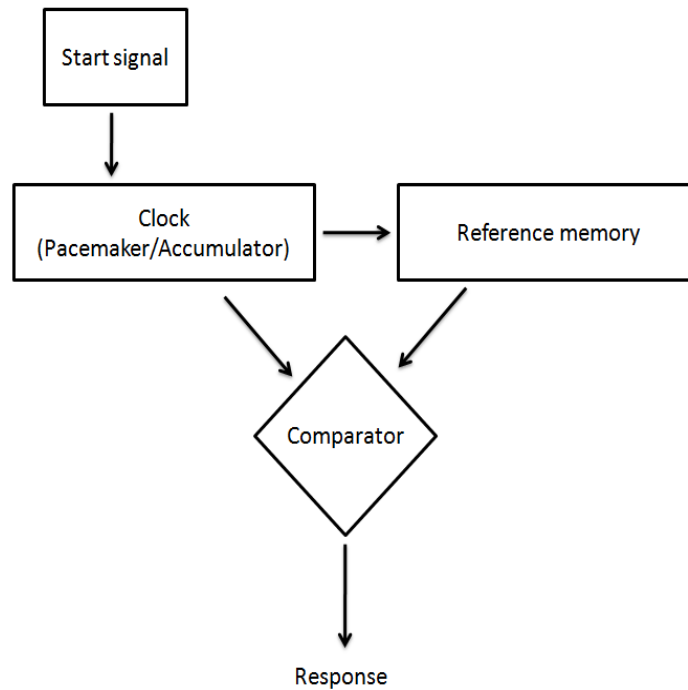
Figure 1.2. The workings of the Scalar Timing Model as seen in Gibbon, 1991 (Figure 9).

The diverse timing models use different mechanisms. In SET, the different processes give feedback to each other. The clock gives feedback to the reference memory and the comparator, and the reference memory also gives feedback to the comparator (Gibbon, 1991). So, when presenting a subject with a CS, the moment that the CS is shown, the subject recalls the memory from the comparator and chooses whether to respond (Kirkpatrick & Church, 1998). In other words, the subjects respond according to when they think the stimulus was supposed to arrive (Gallistel & Gibbon, 2000).

SET was a novel way of looking at how animals and humans store timing information and is well validated (for review see Lejeune & Wearden, 2006; Wearden & Lejeune, 2008). SET predicts that subjects can time intervals, irrespective of the total trial duration (Gallistel & Gibbon, 2000). Church, Meck and Gibbon (1994) tested responses of rats in a peak procedure with varying intervals (15, 30 or 60 s) and with varying trial durations (either 240 s, or eight times the CS interval). Thus, in the latter the training was less frequent but rats still received the same number of trials. Church et al. (1994) found that response rates were accurate for both trial durations; the means and standard deviations for the different durations increased linearly with the total interval duration; thus confirming the predictions made by SET. The scalar timing model has accurately been able to predict human timing results (for review see Allan, 1998; Malapani & Fairhurst, 2002) as well.

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Harris, Gharaei, and Pincham (2011) set up conditioning experiments with varying CS-US intervals to study responses. They found that the frequency of response rates matched the duration of the CSs. Thus, when CS duration varied along a uniform distribution, response rates were also uniformly distributed and when CS duration varied along an exponential distribution, the response rates also varied along exponential distribution (Harris et al., 2011). The results suggest that subjects track the response rate, and not the probability of reinforcement, which is in line with the SET model (Harris et al., 2011).

However, one critical feature of SET and other timing models is that it cannot explain learning, it can only explain timing (Malapani & Fairhurst, 2002) as SET has no learning mechanism beyond coding for temporal features of the stimulus. Studies have shown that cue duration cannot block learning about a stimulus (Williams & Lolordo, 1995). However, studies have also shown that stimulus duration does influence conditioning (McMillan & Roberts, 2010) and that animals sometimes prefer to rely on experimental intervals to predict when a US would occur, instead of cues (Caetano, Guilhardi, & Church, in press). Thus, timing plays an important role in classical conditioning (Machado, 1997) and though timing models explain patterns of responding within trials, more so than associative learning models (Harris & Carpenter, 2011), they do not usually explain learning. Consequently, it would be more parsimonious to account for both timing and associative learning within a single model.

1.5   Hybrid Models

During a simple Pavlovian conditioning experiment, an animal learns that one stimulus is followed by another and it becomes conditioned so that when a CS is presented, it will show a CR in anticipation of the reinforcement (or US) (Pavlov, 1927). Both timing and conditioning models aim to clarify the mechanisms underlying learning. However, timing models predict when and if subjects respond depending on time intervals of cues (Miller & Escobar, 2001), and learning models predict whether subjects respond depending on associative strength between cues (Haselgrove, Esber, Pearce, & Jones, 2010). There are some general principles that are the same for both models. For instance, in conditioned learning, a response is more likely near the time of reinforcement or when a US should appear (Kirkpatrick & Church, 1998). When looking at the experimental setup of an associative versus a timing model they differ in when reinforcement (or the outcome, US) is given (Kirkpatrick & Church, 1998).

Also, an associative conditioning theory can explain the inclination to respond in the presence of a stimulus (CS) and a timing theory is used to explain the incidence of the response (Kirkpatrick & Church, 1998). Furthermore, in associative learning experiments the CS-US association is manipulated to look at response, whilst in timing models the stimulus duration would probably be changed to look at response. In conditioning models they would make predictions about associative strength between stimuli, however in timing models they would make predictions about how subjects assessed durations of stimuli (Kirkpatrick & Church, 1998). Therefore, as Kirkpatrick and Church (1998) point out, neither timing nor associative models accommodate both the cue associations and timing, whilst both are vital for learning. Therefore, hybrid models have been designed to accommodate both and hopefully take into account all variables that are important for learning.

Perhaps one of the more comprehensive models is the Rate Expectancy Theory (RET, Gallistel & Gibbon, 2000). Subjects learn the relationship between CS and US, and responding to stimuli is governed by the expected interval between reinforcements (time from US onset to next US onset) (Balsam, Fairhurst, & Gallistel, 2006) or the ratio of time spent in the experimental context (C) (e.g. intertrial intervals) relative to the duration from CS onset to US onset (or trial time, T); also known as C/T ratio (Balsam, Drew, & Gallistel, 2010; Balsam et al., 2006). Thus, when each US is signaled by a CS, CR will be stronger (when C/T ratios are higher) (Domjan, 2003).

The RET can predict cue competition (Gallistel & Gibbon, 2000); as there is no difference in reinforcement rate for the blocking cue when the target cue is present, the additive combination does not lead to a change in rate, and the reinforcement rate for the target cue is zero. In other words, during acquisition, if the target cue does not influence the blocking cue, i.e. if the rate of reinforcement of the blocking cue is not influenced by the occurrence of the target cue, then no CR will form with the target cue, even when the target cue is paired (reinforced) with a US (Gallistel & Gibbon, 2000). Thus, the target cue is blocked.

There have been very few studies testing whether RET can explain blocking (Balsam et al., 2006; Harris, Andrew, & Livesey, 2012). Harris et al. (2012) set up a Pavlovian conditioning experiment to test whether responding after training with different reinforcement rates would support the RW model (Rescorla & Wagner, 1972) or the RET (Gallistel & Gibbon, 2000). The setup of the experiment was similar to a blocking setup with an intermixed design; subjects were shown compound AB with 100% reinforcement, B and C with 50% reinforcement, and cue D, with 25% reinforcement.

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Cue A and C showed similar response rates, thus providing support for the RET (Gallistel & Gibbon, 2000) as well as the RW (Rescorla & Wagner, 1972) model (Harris et al., 2012).

RET predicts that when stimuli are presented in compound, the rate of reinforcement for the target cue in overshadowing can never be higher that half of the total rate of both cues for the control group which does not have overshadowing. Urushihara and Miller (2007) found that responding to the target cue was greater than control cues, which cannot be explained by RET (Urushihara & Miller, 2007), therefore for that experimental setup the RET was not a suitable model to predict associative learning and timing. Jennings et al. (2007) also found RET could not explain their cue competition results; in their experiments they tested overshadowing in groups with different stimulus durations, and different C/T ratios. Overshadowing was observed in all groups, even though C/T ratios differed. This cannot be explained by the RET.

1.6 Aims

Experimental evidence for the different models has been mixed (see above). Also, most experiments have not tested human associative learning and timing, but tested non-human animals (e.g. Balsam, Drew, & Yang, 2002; Jennings & Kirkpatrick, 2006). Therefore, the aim of the experiments in this thesis were to test an experimental setup which would successfully test learning (see Chapter 2) and timing, and to investigate the role of cue competition on learning and timing by:

(i)   Seeing whether cue competition effects were correlated with timing deficits

(ii)   Investigating whether cue duration affected learning and timing (see Chapter 4)

(iii)   Whether cue location, colour or shape affected learning and timing (see Chapter 3 and 5).

Chapter 2. Basic Experimental Setup: Assessing blocking in humans

2.1 Introduction

Previous researchers have hypothesised that animals and humans possess similar learning mechanisms (e.g. Allan, 1993, 1998; Alloy & Abramson, 1979), and comparison studies have been conducted to test this (e.g. Chapman & Robbins, 1990; Shanks, Pearson, & Dickinson, 1989). Kamin (1969) showed the first evidence for blocking in rats. Since this important finding was made public blocking has been shown in a wide variety of species (e.g. Kehoe et al., 1981; Mackintosh, 1975a). To find support for whether animals and humans have similar learning mechanisms the challenge was to develop a functionally equivalent blocking task for use with human participants. For example, previous conditioning experiments have shown that for both animals and humans, the event contiguity is important and that the frequency with which the contingency is shown will make conditioning stronger (Alloy & Abramson, 1979; Dickinson et al., 1984).

Dickinson et al. (1984) designed a tank paradigm (see Table 2.1) to analyse contingency judgements in people which accommodated varying contingences (i.e. with varying degrees of predictability). Participants had to determine whether a shell or a minefield would be effective in destroying a tank. They found that the participants' ratings were dependent on the strength of the positive contingency. A lower contingency would give rise to lower ratings (Dickinson et al., 1984), thus showing blocking. Further evidence for blocking in humans has also been found by replicating Dickinson et al.'s (1984) study (see also De Houwer & Beckers, 2003; De Houwer, Beckers, & Glautier, 2002; see also Shanks, 1985).

Martin and Levey (1991) hypothesised that human associative learning could be different because animals are not aware of the CS-US relationship, whilst humans are. Thus, they tested participants in an eye lid conditioning experiment with no written instructions (see Table 2.1), which is more similar to nictitating membrane animal studies (e.g. Kehoe et al., 1981). Martin and Levey (1991) used visual stimuli with identical saliency levels to avoid saliency of stimuli influencing cue competition (Denniston, Miller, & Matute, 1996; Mackintosh, 1976; Prados, 2011) and the US was a puff of air. They found that blocking could be shown in the simple experimental setup that was similar to animal experiments.

Table 2.1 Experimental setups of human blocking studies; experimental phases, maximality, additivity and if blocking was found.

Year	Author & Paradigm	V.I.	Exp	PT/practice/ pretreatment	Phase 1	Phase 2	Phase 3	Test	Max Y/N	A Y/N	Blocking Y/N
1969	Kamin				A+	AT+		A, T	N	N	Y
	Abstract (light/ shapes)										
1990	Jones, Gray & Hemsley	Y	Exp 1		A+, C-, D-, E-, F- G-	AB+, CH-, I-, EJ-, FK-, GL-		CB+, DB+, EB+, DI-, EJ-, FK-, GL-	N	N	Y
2000	Waldmann	Y	Exp 1 P, D		P+	PR+, I1I2+		P, R, I1, I2	N	N	Y(P), N (D)
	Alarm										
1992	Waldmann & Holyoak	Y	Exp 3		P+, C-, U-	PR+, C-, U-		P, R, C, U	N	N	Y (P), N(D)
	Allergy/ symptoms/ virus										
1992	Waldmann & Holyoak	Y	Exp 1		P+, C-, U-	PR+, C-, U-		P, R, C, U	N	N	Y
		Y	Exp 2		P+, C-, U-	PR+, C-, U-		P, R, C, U	N	N	Y
2000	Waldmann	Y (D)	Exp 2		S1+, S2-	S1S3+, S2-		S1, S2, S3	N	N	N
		Y(P&D)	Exp 3a		E1 <-C1, E2 <- C2	E1E3 <- C1, E2<- C2		E1, E2, E3	N	N	Y (P), N (D)
		Y	Exp 3b		E1 <-C1, E2 <-C2, E3-	E1E4 <- C1, E2<- C2, E3-		E1, E2, E3, E4	N	N	Y
2003	Lovibond, Been, Mitchell, Bouton, & Frohardt	Y	Exp 1 F	PT: I+, J+, K-, L-	IJ+, JK+, KL-, F-	A+, E+, GH-	AB+, CD+, E+, F-, GH-	A, B, C, D, E, F, G, H	N	Y	Y
		Y	Exp 1 BB	PT: I+, J+, K-, L-	IJ+, JK+, KL-, F-	AB+, CD+, E+, F-, GH-	A+, E+, GH-	A, B, C, D, E, F, G, H	N	Y	N
		Y	Exp 1 F&A	PT: I+, J+, K-, L-	IJ++, JK+, KL-, F-	A+, E+, GH-	AB+, CD+, E+, F-, GH-	A, B, C, D, E, F, G, H	N	Y	Y
		Y	Exp 1 BB&A	PT: I+, J+, K-, L-	IJ++, JK+, KL-, F-	AB+, CD+, E+, F-, GH-	A+, E+, GH-	A, B, C, D, E, F, G, H	N	Y	Y

Year	Author & Paradigm	V.I.	Exp	PT/practice/ pretreatment	Phase 1	Phase 2	Phase 3	Test	Max Y/N	A Y/N	Blocking Y/N
2005	Beckers, De Houwer,	Y	Exp 1	preexposure: -,+,++	A+/++, Z-	AX+/++, KL+/++, Z-		A, X, K, L, Z	N	Y	Y (M & S)
	Pineno, & Miller	Y	Exp 2	PT: G+, H+, GH+/++, I+/++, Z-	A+, Z-	AX+, KL+, Z-		A, X, K, L, Z	Y	Y	Y (A & NA)
		Y	Exp 3 A	PT: G+, H+, GH++, I+, Z-	AX+, KL+, Z-	A+, Z-		A, X, K, L, Z	Y	Y	Y
		Y	Exp 3 SA	PT: G+, H+, GH++, I+, Z-	AX+, KL+, Z-	A+, Z-		A, X, K, L, Z	Y	Y	N
		Y	Exp 4 A		A+, Z-	AX+, KL+, Z-	G+, H+, GH++, I+, Z-	A, X, K, L, Z	Y	Y	Y
		Y	Exp 4 SA		A+, Z-	AX+, KL+, Z-	G+, H+, GH++, I+, Z-	A, X, K, L, Z	Y	Y	Y
	Electrodermal Cond.										
1995	Hinchy, Lovibond & Ter-Horst	Y			A+, AC+, AE+, B-, F-, GH-			A+, B-, C-	N	N	Y
	Eyelid Cond.										
1991	Martin & Levey	N	Exp 1	A, B, C, D (no USs here)	A+, B-	AC+, BD+	C-, D-		N	N	Y
	Lightning machine										
2011	Boddez, Baeyens, Hermans & Beckers	Y	Exp 1 & 2	PT: G+, H+, GH++, Z-	A+, Z-	AX+, KL-, Z-		A, X, K, L	N	Y	Y
	Martians landing										
1997	Arcediano, Matute & Miller	Y		Yes, but no CSs or USs	A+, B-	AX+, BY-		X	N	N	Y

Year	Author & Paradigm	V.I.	Exp	PT/practice/ pretreatment	Phase 1	Phase 2	Phase 3	Test	Max Y/N	A Y/N	Blocking Y/N
	Stock market										
1990	Chapman & Robbins	Y	Exp 1		P+, N-	PB+, NC+		P, B, N, C	N	N	Y
	Tank										
1984	Dickinson, Shanks & Evenden	Y	Exp 2		A+	AX+		A, X	N	N	Y
1985	Shanks	Y	Exp 1		AB+	A+		A, B	N	N	Y
2002	De Houwer, Beckers & Glautier	Y	Exp 1		A+, M-	AT+, KL+, M-		A, T, K, L, M	Y	N	Y (SC), N (MC, SI & MI)
		Y	Exp 2		AT+, KL+, M-	A+, M-		A, T, K, L, M	Y	N	Y (SC), N (MC, SI & MI)
		Y	Exp 3		A+, B-, M-	AT1+, BT2+, KL+, M-		A, T1, B, T2, K, L, M	Y	N	Y (SC), N (SI)
2003	De Houwer & Beckers	Y	Exp 1 & 2		A+, Z-	AT+, KL-, Z-		A, T, K, L, Z	Y	N	Y

A = additivity, BB = backward blocking, Cond. = conditioning, D = diagnostic or invalid, Exp = Experiment, F = Forward, M = maximal, Max = Sub Maximility or testing maximality, MC = maximal + cause , MI = maximal + indicator, N = No, NA = non additivity, P = predictive or valid, PT = pretrain, S = Submaximal, SA = subadditive, SC = submaximal + cause, SI = submaximal + indicator, V.I. = verbal instructions, Y = Yes.

Jones, Gray, and Hemsley (1990) found that the cover story in an experiment may play an important role in blocking in humans (see Table 2.1). They attempted to replicate Dickinson et al.'s 1984 study in which participants had to learn about a cover story, however, they did not find blocking. Jones et al. hypothesised this was because they used a different participant group, namely non-undergraduates as Dickinson et al. (1984) had only recruited undergraduates for their experiments. Also, the cover story could have made it harder for participants to learn the contingencies. To avoid these two possible issues, Jones et al. (1990) developed a new paradigm in which participants were instructed to learn whether there was a simple rule which predicted that the US would appear, and successfully found blocking.

Causality may also be perceived in a different way as a result of how causality questions are phrased to assess participants' predictions; causality may be perceived as a cause- effect or effect- cause (for example Waldmann & Holyoak, 1992) and questions may infer causality (Matute, Vegas, & De Marez, 2002; Vadillo, Miller, & Matute, 2005), and thus influence blocking. De Houwer et al. (2002) conducted experiments to test whether the perception of the cue influenced causality ratings, they presented cues as potential causes of outcomes, or as indicators that did not cause the outcome (see Table 2.1). They found that the target cue elicited a lower rating than two control cues when cues were described as being causes of outcomes, but not when the cues were said to be indicators.

Other studies with people have also failed to show blocking; Hinchy et al. (1995) suggested their participants did not show blocking because participants segregated the learning phases and only attributed causality ratings according to the consecutive phase to the test phase. Therefore, in a following experiment Hinchy et al. (1995) used a single phase design (see Table 2.1), which successfully showed blocking. Hinchy et al. (1995) were also concerned that some cues could distract attention away from the experimental contingencies, because participants inferred causality about certain objects as a result of their semantic knowledge, for example if cues were pictures of every items. Thus, Hinchy et al. used coloured squares in the final setup, which also successfully showed blocking. The experiments in this thesis also used coloured squares as cues in most experiments presented in the following chapters, and were based on those by Boddez, Baeyens, Hermans, and Beckers (2011) who used coloured shapes.

The outcome maximality or the US is also very important in human associative learning experiments (Cheng, 1997; Waldmann, 2000), see Table 2.1. Cheng (1997) hypothesised that causality inference could be different when the outcomes vary in

strength. De Houwer et al. (2002) tested this (see Table 2.1); in their experiments half of the participants were told the maximum outcome was 20/20, but participants were only shown an outcome of 10/20 and the other half of the participants were informed the maximum outcome was 10/10, and participants were shown a maximum outcome of 10/10. They found that when outcome was submaximal (10/20), blocking was stronger than when it was maximal (10/10). This is called the maximality effect.

Pre-training phases have also been found to influence the strength of cue competition, and more specifically, blocking (Beckers, De Houwer, Pineno, & Miller, 2005; Lovibond, Been, Mitchell, Bouton, & Frohardt, 2003). When participants are presented with a higher outcome in a pre-training phase, this enables them to allocate a higher causal probability to compound cues, and in addition creates a causality for the target cue that is much lower than the outcome seen in trials after pre-training (Lovibond et al., 2003), see Table 2.1. This is referred to as the additivity effect, and increases the likelihood of blocking.

Animal studies have shown that when blocking and target stimulus durations differ in associative learning tasks, this can influence cue competition, showing that temporal factors are very important in learning. For example, Jennings and Kirkpatrick (2006) tested whether a longer or shorter blocking cue (compared to the target cue) would influence blocking. They found that, CS1 blocked CS2 when it was longer, but blocking was attenuated when CS1 was shorter than CS2. To test whether animals and humans share learning mechanisms (e.g. Allan, 1993, 1998; Alloy & Abramson, 1979), the same results should be observed in human studies as in animal studies (Jennings et al., 2007; Jennings & Kirkpatrick, 2006; McMillan & Roberts, 2010). Therefore, an experiment needed to be set up which would enable testing of blocking and in which stimulus durations could easily be changed between conditions.

Therefore, an associative learning experimental setup was adapted to include duration tests that would test temporal estimates of different cues. Human timing experiments usually involve subjects reproducing time intervals (e.g. Koch, Oliveri, Carlesimo, & Caltagirone, 2002), comparing two consecutive intervals (Morillon, Kell, & Giraud, 2009) or estimating time intervals (e.g. van Rijn & Taatgen, 2008). In timing tasks where participants have to reproduce absolute intervals, they are trained to learn the interval, and then have to reproduce the interval by pressing a button when they think the interval should be finished (van Rijn & Taatgen, 2008). In this case, the learned and reproduced intervals are compared to see how accurate participants are (van Rijn & Taatgen, 2008).

As mentioned above, there are also common timing tasks which involve comparing durations. For example, when participants are asked to estimate time intervals participants have to distinguish between absolute time intervals (Grube, Cooper, Chinnery, & Griffiths, 2010); participants are required to indicate whether a stimulus is shorter or longer than a learned target interval. A threshold will then be observed; under this threshold participants will indicate the intervals are shorter, and over this threshold participants will indicate intervals are longer. Discrimination tasks are also used to test timing accuracy; Morillon, Kell & Giraud (2009) presented subjects with two stimuli at the same time and subjects indicated which of two stimuli was presented on screen for longer by pressing a button indicating which stimulus was longer. Difference in duration between consecutive stimuli and accuracy could then be determined (Morillon et al., 2009).

The duration test conducted in the experiments described in this chapter followed those of standard timing investigations (e.g. Jones & Wearden, 2003, 2004; Ogden, Wearden, & Jones, 2008). In standard timing investigations participants are shown stimuli with standard durations and then in a second phase are asked to judge whether stimuli are of a longer, shorter or the same duration. This approach was adopted in experiments in this thesis; specifically, during the duration test, participants had to distinguish whether the duration of the stimuli they saw was shorter, the same or longer than the duration of the stimuli in training.

The experiments and results in this first experimental chapter tested whether the experimental setup was successful in creating a blocking effect, testing whether previous results could be replicated, and provided the baseline experiments. Boddez et al. (2011) conducted the experiment with Dutch instructions and Flemish participants. Therefore, it was not certain that when the experiment was translated to English, and participants were students from Newcastle University, that blocking would occur. Temporal estimates were also tested, and were not predicted to differ between stimuli or groups. The SET model (Gibbon, 1991) does not predict any difference in temporal estimates between cues when they are of the same modality and are presented for the same duration, which was the case in the experiments described below.

Participants' certainty was also tested when they estimated the durations. Participants were to give feedback about how certain they were as it was predicted that participants might be more certain scoring durations of cues that were seen as more important, such as the blocking and target cue. It was also predicted that participants

would be more certain when they got answers correct than when they got answers wrong.

2.2   Experiment 2.1

The paradigm adopted in the present experiment has successfully produced a blocking effect in a Dutch speaking population (Boddez et al., 2011). Therefore, the experimental protocols were translated from Dutch into English and an experiment was conducted in order to establish if the English version of this task would produce similar cue competition effects. The experiments consisted of three phases (Beckers, De Houwer, et al., 2005; De Houwer et al., 2002); the first phase was a pre-training phase which was intended to maximise the possibility of observing a blocking effect via the additivity effect (discussed in the introduction) (Beckers, De Houwer, et al., 2005; Lovibond et al., 2003). This was achieved by showing participants a maximal outcome during pre-training, i.e. '++' (two lightning bolts), which was not shown during subsequent training phases. In addition, participants were also shown two other possible outcomes, namely '+' (one lightning bolt) or '-' (no lightning bolts). The pre-training phase was followed by an elemental phase which showed the stimulus which caused blocking. After the elemental phase, the subjects were presented with two sets of compound cues; the blocking and target cue, and two control cues. Lastly, the participants completed a test phase in which they were presented with individual CSs (Beckers, Van den Broeck, et al., 2005; De Houwer et al., 2002).

2.3   Method

Participants

Fourteen participants took part in this experiment, eight female and six male. Participants' ages ranged from 18 to 46 years old ($M = 23.57$, $SD = 8.96$). The subjects were Psychology, Medicine or Dentistry students at Newcastle University. Participants were recruited via an online volunteer scheme or in the computer cluster in the Newcastle Medical School. Participants were paid four pounds for their participation.

Apparatus

The experiment was programmed and run in E-prime (v2.0 Professional, Psychology Software Tools Inc., Pittsburgh, PA) on an MS Windows XP platform. The experiments were conducted on a RM desktop pc with a 19" Colour Dell LCD monitor

which was approximately 60 cm from the participant. Participants responded via the keyboard and mouse during the experiment.

Stimuli

A clip art picture of a magician was shown on the left of the screen, and measured 7.2 by 10.7 cm. To the right of the magician, eight cues were presented side by side along the top of the screen in a row. There was a 1 mm gap between the picture of the magician and the cues. Each cue had a different colour and a distinct shape. From left to right these were: parallelogram, hexagon, triangle, pentagon, circle, trapezoid, square and a cross (see Figure 2.1a). When the cues were inactive they were white with a grey outline (see Figure 2.1a), and when they were active they were coloured (see Figure 2.1b). The squares in which cues were presented measured 3.7 by 3.9 cm.
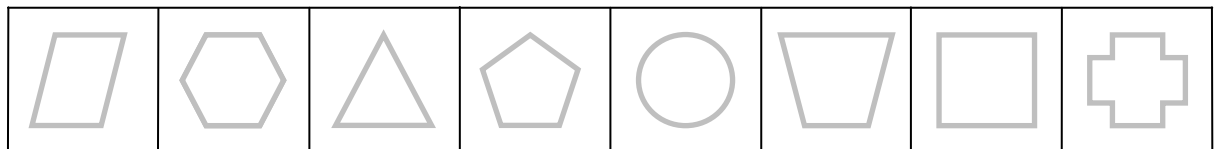
Figure 2.1a. The different cues presented on screen when they were not active.
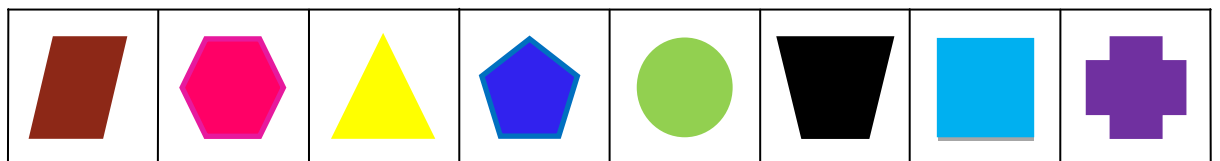
Figure 2.1b. The different cues with their respective colours when they were active.

For the positive stimuli, the unconditioned stimulus (US) was one or two lightning bolts that appeared on the screen (see Figure 2.2a and 2.2b). The US (one lightning bolt) measured 14.5 cm and was 2.5 cm at its widest point, and was always presented in the middle of the screen. Non reinforced stimuli were followed by a black screen (see Figure 2.2c).

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Figure 2.2a. One lightning bolt used for positive reinforcement (+) US.

Figure 2.2b. Two lightning bolts used for positive reinforcement (++) US in the pre-training phase.

Figure 2.2c. No lightning bolts used for negative control (-) US.
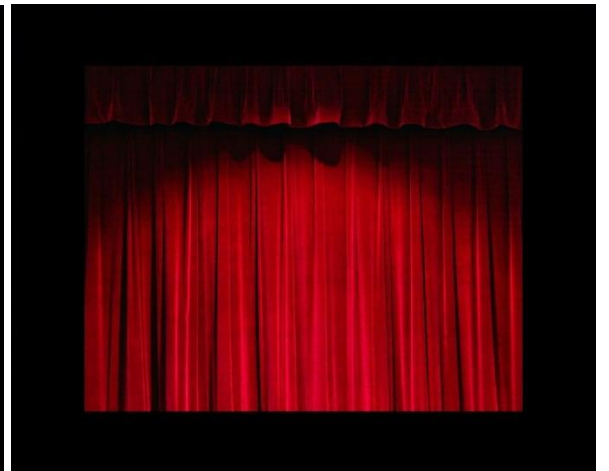
Figure 2.2d. Curtains closed for the test phase when participants cannot see the US.

Procedure

A maximum of two participants were tested at the same time but were instructed not to talk whilst the experiment was running. Participants were asked to read onscreen instructions and were informed verbally that throughout the experiment there would be instructions explaining each section in detail (see appendix for full instructions). They were explicitly told to ask the experimenter questions if anything was unclear before or during the experiment.

Colour test

Because the experiment employed coloured stimuli a colour test was conducted prior to the experiment beginning. During the colour test each participant was shown ten different pictures. Each picture showed a coloured object, the colour of which the participants were required to identify by typing the colour name. Once the participant had completed this task they automatically proceeded to the training phase of the experiment. Participants' data was not analysed if the participant did not answer all the colour test questions correctly.

Training and Testing

Cover story

The paradigm and cover story for this experiment were adapted from an experiment designed by Tom Beckers (Katholieke Universiteit Leuven) (Boddez et al., 2011). The experiment was in Dutch; therefore the original instructions were translated from Dutch to English. Participants were told that a magician had built a lightning machine which could make lightning bolts appear. They were told the machine had eight different buttons with a distinct shape. If the magician pressed one or more of the buttons, the button he pressed lighted up, each in its own colour. Participants were informed that after the buttons had lighted up that they would either see one lightning bolt, two lightning bolts or no lightning bolts.

Instructions

Additivity instructions were presented, similar to those of Mitchell and Lovibond (2002), and identical to those of Boddez et al. (2011). Participants were told explicitly that by pressing the correct buttons, the magician could make lightning bolts appear so their job was to find out exactly how the machine worked by observing which button the magician pressed and whether lightning would appear. They were also told they had to predict when lightning would appear depending on which button the magician pressed. Participants were informed they could make their predictions using a range from zero to ten on a Likert scale; in which zero was 'I definitely don't expect a lightning bolt', five indicated 'I don't know' and ten indicated 'I am certain there will be a lightning bolt', see Figure 2.3.
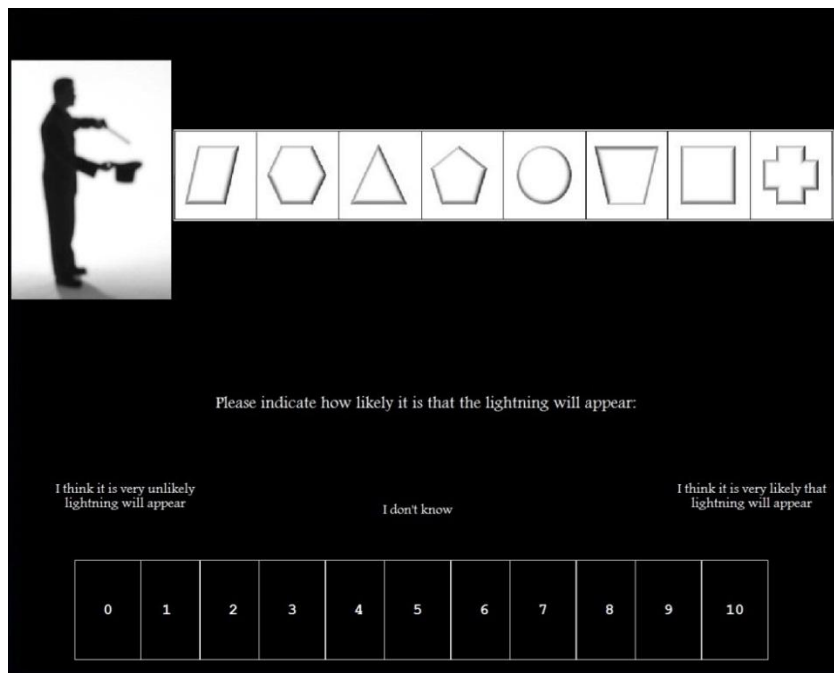
Figure 2.3. Likert scale prediction screen with boxes along the bottom of the screen ranging from zero to ten.

After giving causal ratings for the different cues (blocking test phase), participants had to give feedback about the duration of stimuli (duration test phase). Therefore, in the instructions before they started the pre-training phase, they were also instructed to pay attention to the duration of the stimuli. The onscreen instructions informed them the magician had noticed that the duration for which the buttons were on for influenced the occurrence of the lightning, and thus it was important to pay attention to the duration. Thus, participants were also informed their temporal estimates would be tested in the last part of the experiment (the duration test).

Trial Duration

Participants were initially shown the buttons of the lighting machine in the 'off' position for 500 ms – in this instance each button was coloured white. To simulate that the magician had selected and pushed one or more buttons, the button(s) would change colour and remain illuminated for 1900 ms. At this point the evaluation scale appeared on the screen and the subjects rated the likeliness of lightning appearing by clicking within one of the evaluation scale boxes on screen. As soon as the subjects had clicked on one of the boxes, their choice would be highlighted in grey for 1000 ms, and then they were shown the US; lightning bolt(s) or a black screen. The USs were also all shown for the same duration, 2500 ms and the ITI was shown for 1500 ms, see Figure 2.4.

Buttons white	Buttons coloured	Buttons white	Prediction	Lightning shown or not	Screen black
	CS			US	ITI
500	1900	500	unlimited	2500	1500

Figure 2.4. Durations for different stimuli (CSs), USs and intertrial intervals (ITI) during the experiment. All times in bottom row are in milliseconds.

Pre-training phase

It has been demonstrated that including an example of the potential outcomes enhances the blocking effect in humans (Beckers, De Houwer, et al., 2005; Boddez et al., 2011; Lovibond et al., 2003). Therefore, a pre-training phase was included immediately prior to the experiment. During this phase, participants saw three cues and three different outcomes:

(i)   a single cue was paired with one lightning bolt (CS+).

(ii)   two cues were presented simultaneously and paired with two lightning bolts (CS++).

(iii)   a single cue was presented with no lightning bolt (CS-).

Participants saw each of the three CS-US (+, ++ or -) pairings six times. Following the presentation of a CS or two CSs they were asked to rate the probability that the US would then be presented.

Elemental phase

In the elemental phase the blocking cue was presented six times with one lightning bolt as outcome. The negative control was presented six times with no lightning bolts as outcome.

Compound phase

In the compound phase, the blocking and target cues were presented six times in a simultaneous compound (see Figure 2.5), with the outcome of one lightning bolt. The matched overshadowing controls were also presented six times, with the outcome of one lightning bolt. The negative control was shown individually, followed by a picture of open curtains with no lightning bolt.
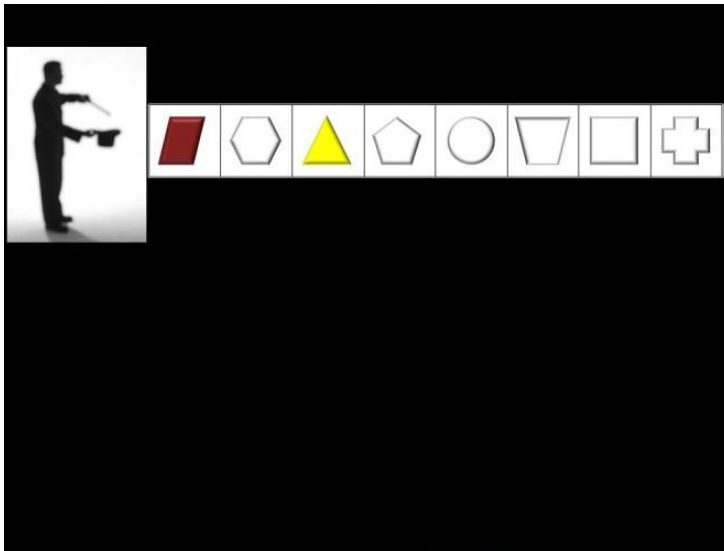
Figure 2.5. Example of compound CSs (two buttons being pressed).

Test phase

The blocking cue, target cue, two overshadowing controls, a negative control and a new cue that had not been shown before were presented individually and only once in the test phase. Each stimulus was followed by a closed curtain outcome, i.e. with a hidden US. The new cue was shown to confirm that participants would still respond to the new cue with a score of five ('I don't know whether lightning will appear'). See Table 2.2.

Table 2.2. Table outlining experimental setup with different training phases and stimuli per phase. One plus (+) indicates one lightning bolt was shown as a US, two plusses (++) indicates two lightning bolts were shown and a minus (-) indicates no lightning was shown. The different letters in the table represent: blocking cue (B), overshadowing compound cues (O1 and O2), target cue (T), control cue (C), pre-training cues (P1 and P2) and negative control (N).

Pre-training	Elemental	Compound	Test
P1+	B+	BT+	B
P2+	N-	O1O2+	O1
P1P2++		N-	T
N-			O2
			C
			N

Timing Test

After the participants were shown an individual cue (or lightning machine button) for a certain length of time, a question screen appeared asking them if they thought the duration they just saw (the duration that the button was on/coloured) was the same for that cue as seen in the previous part of the experiment. They were instructed to type yes or no. The second question asked how certain they were of their answer. They were asked to type in any number from zero to 100; zero being the lowest score if they were uncertain about their answer and 100 when they were very sure of their answer. After they pressed shift to submit their answer, they were shown a hidden US followed by the ITI.

For the duration test participants were shown three possible durations; a shorter one which was 1400 ms, a target duration which was 1900 ms and a longer duration which was 2400 ms. In this part of the experiment participants were shown: the blocking cue, the target cue, the two overshadowing controls, a negative control and a control cue participants had only seen in the previous test phase.

There were four counterbalancing conditions in this experiment ensuring there could be no bias for certain shapes or left or right side of the screen. An ANOVA showed there was no difference between counterbalancing conditions for blocking scores ($F < 1$), and two ANOVAs showed there was no difference between counterbalancing conditions for confidence scores in the timing test ($F(3, 10) = 1.68$, $p = 0.23$), and no difference in percentage of wrong answers ($F < 1$).

Data analysis

All data analysis was run in IBM SPSS Statistics Version 19.

Elemental training

Causality ratings for the blocking and negative control cues in the elemental phase were compared with an ANOVA.

Blocking test

Blocking was calculated using causality ratings of different stimuli following De Houwer et al. (2002); (O1+O2)/2) – T), where O1 and O2 were overshadowing controls

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and T was the target stimulus. This blocking score was then compared to zero in a two-tailed one sample t-test. An ANOVA was conducted to analyse correct and incorrect responses for temporal estimates. Two separate ANOVAs analysed temporal estimates of three test durations (shorter, target and longer).

Confidence test

A two-tailed one sample t-test was used to analyse confidence scores. Participants' certainty of temporal estimates of blocking and target cue, and the two overshadowing cues were analysed with ANOVAs. Certainty ratings for temporal estimates were analysed with a two-tailed one-sample t- test for the blocking cue, target cue and the two overshadowing cues. Percentage of incorrect temporal estimates for blocking and target cue, and the two overshadowing cues were analysed in ANOVAs, and a two-tailed one sample t-test was done to look at percentage of correct answers for blocking, target and two overshadowing cues.

Ethics were approved for all experiments in this thesis by Newcastle University Medical School Ethics Committee.

2.3.2   Results

Pre-training phase

The causality ratings were submitted to a 4 cue (P1, P2, P1P2 and N) x six Trial $(1-6)$ within- subjects analysis of variance (ANOVA) with both Cue and Trial as repeated measures. The ANOVA showed that there was a difference between the six trials in the pre-training phase (Trials $F(5, 260) = 2.65$, $p = 0.02$ with). There was also a difference between cues when comparing causality ratings with an ANOVA; Cue $F(3, 52) = 477.73$, $p<0.001$, see Figure 2.6.
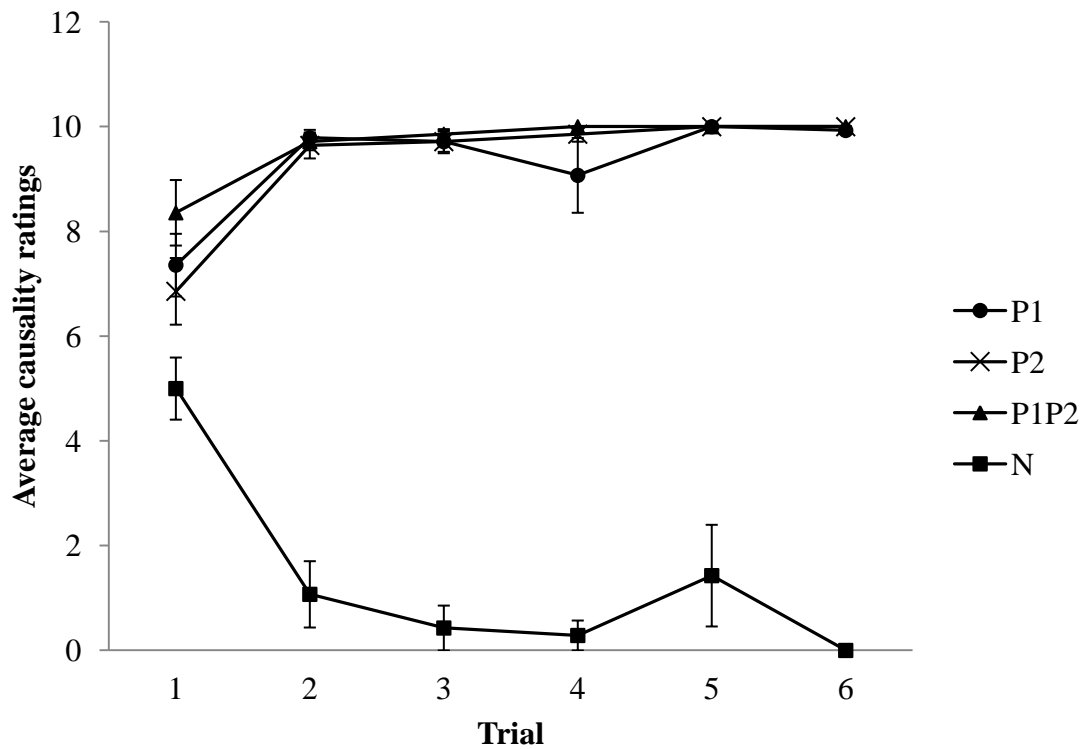
Figure 2.6. Mean causality ratings for pre-training cues (P1, P2 and P1P2) and negative control cue (N) in the pre-training phase. Error bars show ±1 *SEM*.

Elemental phase

The causality ratings were submitted to a two Cue (B and N) x six Trial (1- 6) within subjects ANOVA with both Cue and Trial as a repeated measures. There was a significant difference between causality ratings for the blocking and negative control cue in the elemental phase indicating that participants learned which cue was associated with which outcome ($F(1, 26) = 8096.42$, $p < 0.01$, Figure 2.7). There was a significant difference between the causality ratings for the blocking cue over trials ($F(5, 78) = 78.14$, $p < 0.001$) and there was no difference between trials for the negative control as all ratings were zero ($F < 1$).
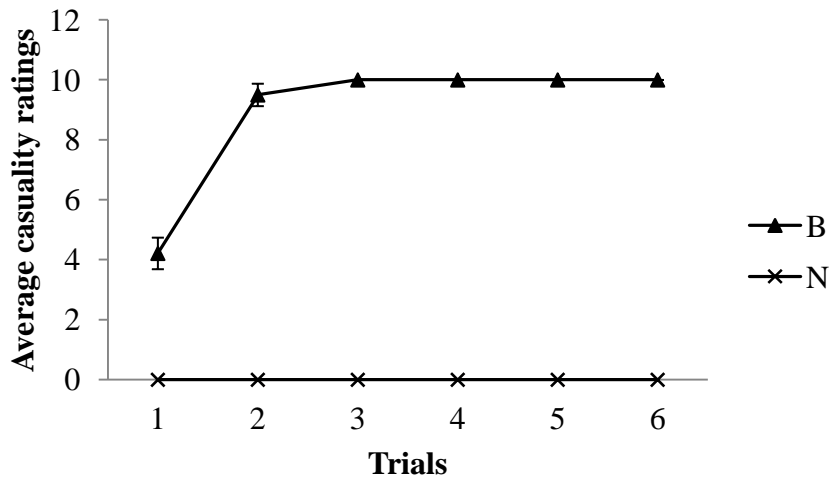
Figure 2.7. Mean causality ratings for blocking cue (B) and negative control cue (N) in the elemental phase. Error bars show ±1 *SEM*.

Compound training

When comparing the causality ratings across different trials in the compound phase, the ratings were submitted to a three Cue (BT, O1O2 and N) x six Trial (1 − 6) within subjects ANOVA. This showed there was a difference between the trials: Trials $F(5, 195) = 23.28$, $p < 0.001$. The ANOVA also showed that there was a difference in causality ratings between the two sets of compound cues (BT and O1O2) and the negative control (N); Cues $F(2, 39) = 2220.00$, $p < 0.001$, see Figure 2.8.
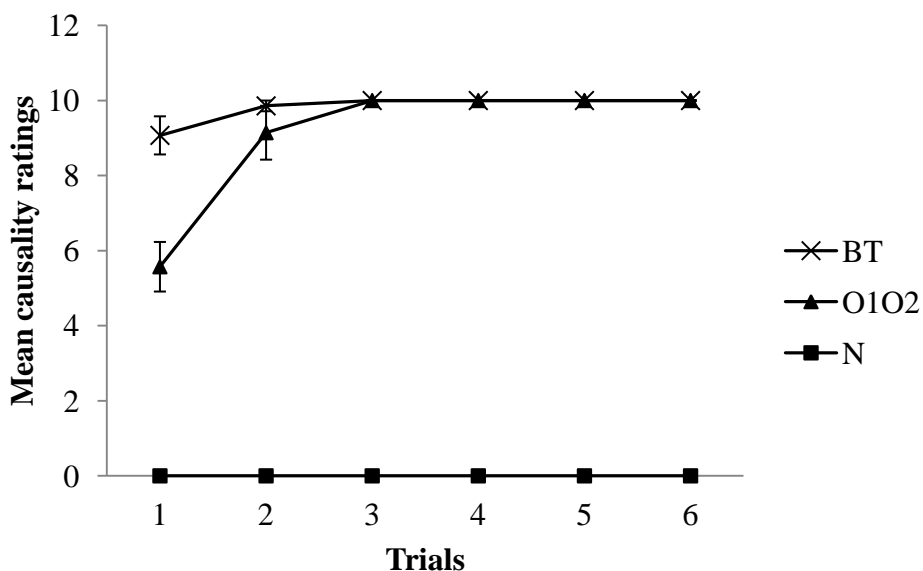
Figure 2.8. Mean causality ratings for compound cues blocking cue and target cue (BT), compound overshadowing cues (O1 and O2) and negative control cue (N) in the compound phase. Error bars show ±1 *SEM*.

Blocking

Participants rated the overshadowing controls higher than the target cue; $t(13) =$ 9.58, $p <$0.001, and the blocking score was 5.86.

Temporal estimation

When comparing the percentage of incorrect answers for the three different test durations (averaged across all stimuli), participants were not better at estimating the duration for the shorter, target or longer duration; there was no main effect of Duration ($F < 1$) on percentage of incorrect answers, see Figure 2.9. Thus, participants gave the same number of correct and incorrect responses for each of the three durations.
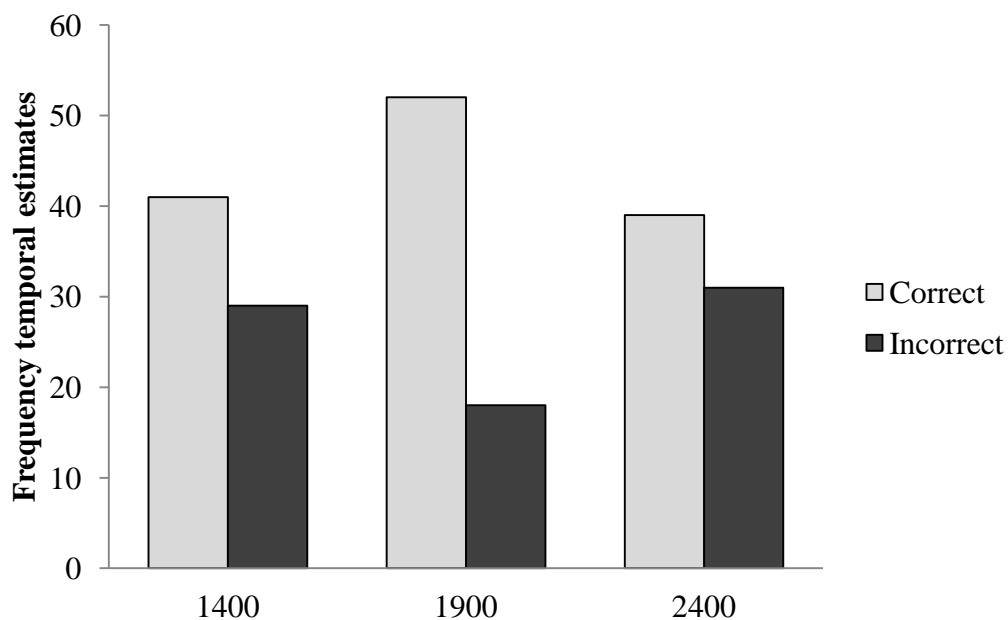
Figure 2.9. Frequency of correct and incorrect temporal estimates in Experiment 2.1 for test durations (in ms).

Certainty of estimates

People were as certain judging the duration of the target duration as estimating the duration of the shorter or longer duration ($F < 1$). When comparing certainty ratings people had entered, ratings were significantly higher than 50% for every time test duration (shorter: $t(13) = 7.14$, $p < 0.001$, target: $t(13) = 6.51$, $p < 0.001$ and longer: $t(13) = 6.38$, $p < 0.001$).

The certainty scores were also subjected to a two Cue (B and T) within subjects ANOVA with Cue as a repeated measure. There was no difference when comparing certainty of temporal estimates for blocking and target cues ($F(1, 13) = 1.37$, $p = 0.26$); blocking cue $M = 76.67$, $SD = 14.86$ and target cue $M = 72.50$, $SD = 17.32$. The overshadowing cue estimates were analysed in an identical way; the certainty scores were subjected to a two Cue (O1 and O2) within subjects ANOVA with Cue as a repeated measure. There was no difference between certainty of temporal estimates for the two overshadowing cues ($F < 1$); first overshadowing cue $M = 67.86$, $SD = 16.32$ and second overshadowing cue $M = 71.29$, $SD = 14.18$.

The ratings were analysed with a one sample t-test comparing the ratings to 50 %. The certainty ratings were significantly higher than 50% when looking at ratings per stimulus (blocking cue: $t(13) = 6.71$, $p < 0.001$, target cue: $t(13) = 4.86$, $p < 0.001$, first overshadowing cue: $t(13) = 3.92$, $p = 0.002$ and second overshadowing cue: $t(14) = 6.29$, $p < 0.001$. Therefore, participants were confident about their temporal estimates for the different cues.

The temporal estimates for the various cues were also compared using a two Cue (either B and T, or O1 and O2) ANOVA with Cue as a factor. When analysing accuracy of temporal estimates, there was no difference in the accuracy in temporal estimates for blocking and target cue ($F < 1$). There was also no difference in accuracy when comparing the two overshadowing cues ($F(1, 13) = 1.68$, $p = 0.22$), see Figure 2.10.

A one sample t-test showed that the percentage of incorrect temporal estimates for blocking and first overshadowing cue did differ from 50% (blocking cue: $t(13) = -2.60$, $p = 0.02$ and first overshadowing cue: $t(13) = -3.37$, $p < 0.01$), and target and second overshadowing cue did not ($t(13) = -1.55$, $p = 0.15$ and $t(13) = -1.31$, $p = 0.21$ respectively). Therefore, participants were more accurate at assessing the duration of the blocking cue and one of the overshadowing cues than the target cue and the second overshadowing cue.
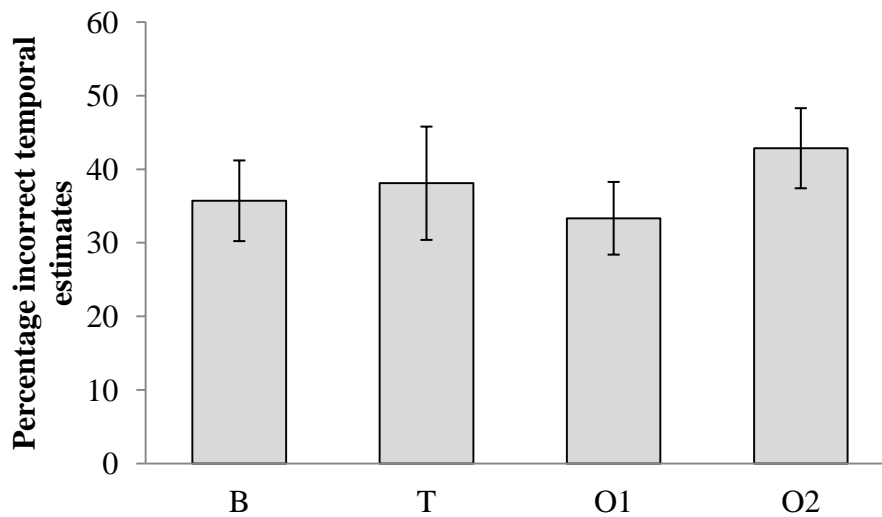
Figure 2.10. Percentage incorrect responses for temporal estimates of blocking (B), target (T) and first overshadowing (O1) and second overshadowing (O2) cue. Error bars show ±1 *SEM*.

2.3.3 Discussion

The results for the pre-training phase were as expected; the pre-training cues were rated higher than the positive control and the ratings differed across trials. Analysis of the elemental phase showed that participants learned which cue had a positive outcome and a negative outcome because there was a difference in causality ratings between the two cues. The compound phase analysis showed that participants learned that the two sets of compound cues would be followed by a lightning bolt, and the negative control cue would not. Therefore, the causality ratings for the compound phase indicated that participants learned which cues predicted USs. Analyses for the pre-training, elemental and compound phases were not conducted for any following experiments as the results were observed to be very similar.

The results showed higher causality ratings for the blocking cue, and lower causality ratings for the target cue than the two overshadowing controls. Therefore, the experimental paradigm adopted in the presented experiment reliably produced a robust blocking effect. This is in line with previous studies that had a similar setup indicating that the procedure was transferred readily from Dutch to English speaking participants (Beckers, De Houwer, et al., 2005; Boddez et al., 2011; De Houwer et al., 2002).

Participants gave more correct than incorrect responses, and there were an equal number of correct responses for each of the three test durations (shorter, target and

longer). Furthermore, participants expressed a high degree of certainty in their answers. Participants were very certain about their ability to assess the durations correctly as they scored the durations correctly, therefore their confidence was found to be justified.

There was no difference in certainty ratings when comparing compound cue pairs, participants were as certain about their estimates for the blocking as the target cue, and participants gave identical certainty ratings for the two compound control cues. Also, participants were very confident rating the temporal estimates as they all gave ratings higher than 50%. Participants were not equally accurate at estimating the durations for the compound cues. The percentage of incorrect answers did not differ from 50% for the target and second overshadowing cue, was this was not the case for the blocking and first overshadowing cue. Yet, there was no difference in percentages when comparing the compound cue pairs directly.

To summarize, participants showed the same accuracy when comparing temporal estimates between stimuli and were confident in their estimates. However, they were not as accurate at estimating durations of cues in compound cue pairs. In this experiment it was not possible to analyse whether participants thought stimulus durations were longer or shorter than the test durations, seeing that the duration test only asked for feedback about whether they thought it was the same duration or not.

Thus, to enable more thorough analysis of temporal estimates, the duration test was changed to allow the participants to choose from a scale of options ranging from shorter, through actual, to longer. Instead of a simple binary, yes or no answer; it could be determined whether participants were better or worse at judging particular durations. This would also allow a determination as to whether participants were generalizing the duration assessment of individual stimuli.

2.4 Experiment 2.2

This experiment tested whether a different duration test would show accurate temporal estimates in a blocking task. The setup for this experiment was almost identical to the setup in Experiment 2.1. However, the duration test was changed slightly. In Experiment 2.1 participants would simply answer 'yes' or 'no' to the question whether they thought a duration they were shown was identical to a duration in the training phase. In this experiment participants were asked to assess the duration by pressing in a box on a Likert scale which ranged from 'shorter', 'actual', to 'longer'. Thus, participants judged duration in more detail than in Experiment 2.1.

2.4.1 Method

Participants

Twelve people took part in this experiment, seven females and five males. Age ranged from 22 to 66 years ($M = 36.08$, $SD = 13.14$). Participants were Psychology, Medicine or Dentistry students at Newcastle University and other participants were recruited via an online volunteer scheme. Volunteers were paid four pounds as a thank you.

Stimuli

Training and testing for blocking was identical to Experiment 2.1.

Procedure

The procedure for training and testing (the first two parts of the experiment) were identical to Experiment 2.1, however the procedure for the duration test differed in Experiment 2.2. For the duration test in Experiment 2.2 participants were shown each stimulus three times, each time for a different duration (1400, 1900 and 2400 ms); identical to Experiment 2.1. However, the test question did differ from Experiment 2.1. In the new setup, following the offset of the stimulus, participants were asked to estimate how long the button had been switched on for. Estimates were made on a nine point Likert scale where a score of one indicated that the duration was shorter than in the training phase and cue competition test, five, when they thought the duration was the same, and nine when they thought the duration was longer. After participants had selected one option (or a score) on the Likert scale, they were shown a hidden US (closed curtains) followed by the ITI. This part of the experiment ended when participants had viewed and scored every stimulus, except for the two pre-training cues, three times.

Data analysis

Temporal estimates

Participants' assessments of temporal estimates of the two overshadowing and blocking and target cue were analysed separately. For both sets of cues, temporal estimates were compared with an ANOVA.

2.4.2 Results

Training

An ANOVA was conducted with a two Cue (B and N) x six Trial $(1 - 6)$ within subjects ANOVA with both Cue and Trial as repeated measures. There was a difference between the causality ratings for the blocking and negative control cues across trials $(F(1, 20) = 3412.34, p < 0.001)$. Causality ratings between trials for the blocking cue also differed $(F(5, 60) = 21.35, p < 0.001)$, but causality ratings between trials for the negative control cue did not differ as all ratings were zero, see Figure 2.11.
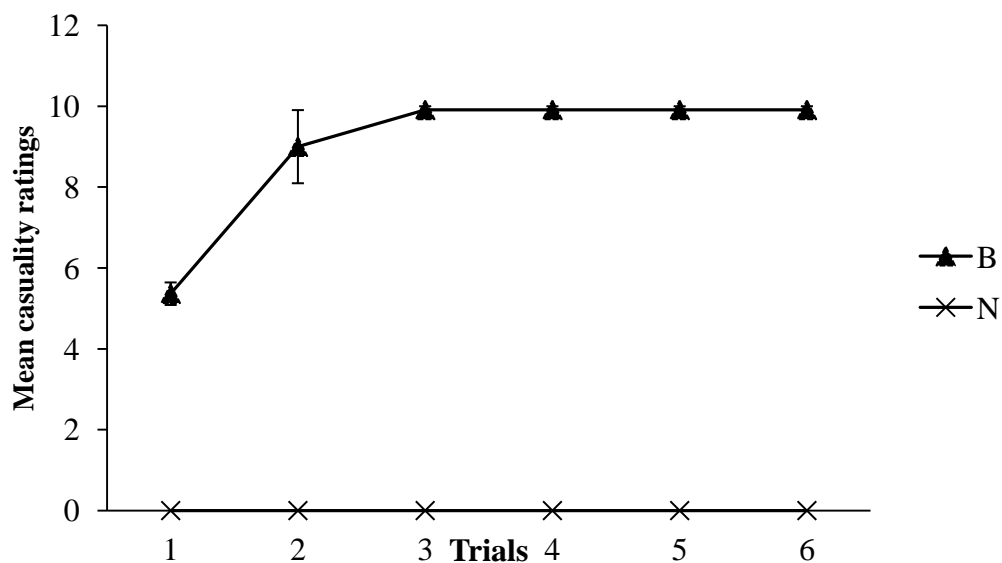
Figure 2.11. Mean causality ratings for blocking (B) and negative control (N) cue during elemental phase trials. Error bars show ± 1 *SEM*.

Blocking

Mean causality ratings were higher for the two control cues (O1 and O2) than the target cue; the mean blocking score was 2.43 ($SD = 2.81$). A significant blocking effect was found; $t(11) = 3.45$, $p < 0.01$, see Figure 2.12.
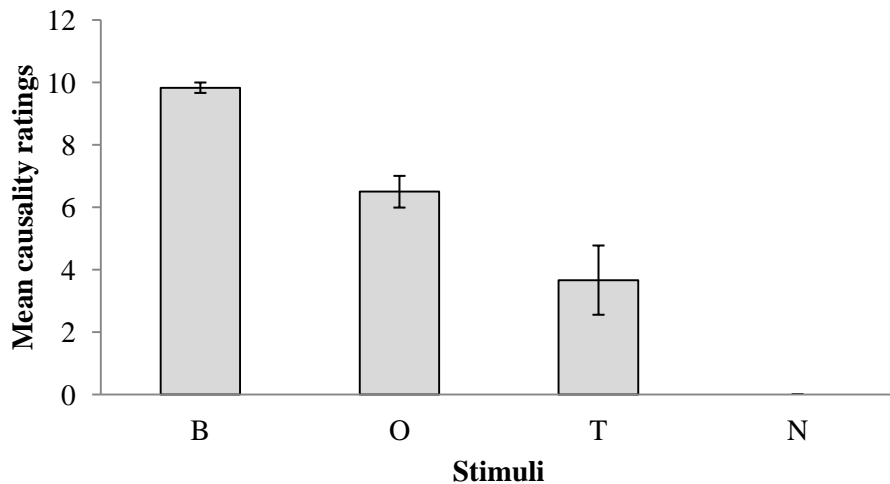
Figure 2.12. Mean causality ratings during test phase for blocking cue (B), mean of the overshadowing cues (O), target cue (T) and negative control (N). Error bars show ±1 *SEM*.

Temporal estimates

Overshadowing cues

The mean temporal estimate for the first overshadowing cue was 4.94 ($SD = 1.07$) and for the second cue was 5.33 ($SD = 1.13$). The temporal estimates for the overshadowing cues were submitted to a two Cue (O1 and O2) ANOVA with Cue as a factor. Means of temporal estimates did not differ between the two overshadowing cues ($F(1, 11) = 3.23$, $p = 0.1$).

A student t-test showed both means did not differ from five; first overshadowing cue $t(11)$ -0.18, $p = 0.86$ and second overshadowing cue $t(11) = 1.02$, $p = 0.33$.

Blocking & target cue

The temporal estimates for the blocking and target cue were submitted to a three Duration (1400, 1900 and 2400 ms) ANOVA with Duration as a factor. Participants' temporal estimates were accurate for the blocking cue as there was a difference in

estimates between the three test durations ($F(2, 22) = 9.60$, $p < 0.01$). There was also a difference between temporal estimates when analysing the target cue estimates ($F(2, 22) = 28.87$, $p < 0.001$). Means and standard deviations of blocking and target cue were similar when averaging across the three durations; mean of blocking cue was 5.30 ($SD = 1.31$) and target cue was 5.14 ($SD = 0.94$).

The standard deviations of the temporal estimates were submitted to a two Cue (B and T) ANOVA with Cue as a factor. There was no difference in standard deviations when blocking and target cue were compared ($F(1, 11) = 1.16$, $p = 0.30$).

Accuracy of estimates for the target duration were also analysed by comparing target duration estimates of the blocking and target cue to five with a student t-test (the midpoint score on the Likert scale) and no difference was found; blocking cue: $t(11) = -0.16$, $p = 0.87$ and target cue: $t(11) = 1.77$, $p = 0.10$.

The target duration temporal estimates were also submitted to a two Cue (B and T) ANOVA with Cue as a factor. When comparing target duration (1900 ms) temporal estimates for blocking and target cue to each other, no difference was found between the two cues ($F < 1$); mean target duration estimate for blocking cue was 4.92 ($SD = 1.78$) and for target cue was 5.33 ($SD = 0.65$). Therefore, in this experiment participants were accurate at estimating durations for every stimulus.

2.4.3   Discussion

Experiment 2.2 showed blocking and results were similar to those found in other human cue competition experiments (Beckers, De Houwer, et al., 2005; De Houwer & Beckers, 2003; De Houwer et al., 2002). The temporal estimates for the blocking and target cue showed that participants were accurate at distinguishing between the three test durations. The results also showed that there was no difference in temporal estimates between blocking and target cue.

Blocking and timing results were in line with previous experiments and predictions from associative learning models (e.g. Mackintosh, 1975b; Rescorla & Wagner, 1972). Therefore, this and similar setups were used in following experiments. In future experiments the influence of cue properties on cue competition and timing was going to be tested, hence the paradigm's generalisability needed to be investigated. Consequently, in the next experiment (Experiment 2.3) a new set of stimuli were used to test whether the same or similar cue competition and timing results could be obtained to those of Experiments 2.1 and 2.2.

2.5   Experiment 2.3

In previous studies it has been reported that a more salient stimulus (i.e. stimuli that subjects/ participants paid more attention to) was more effective in conditioning than a less intense stimulus (Denniston et al., 1996; Mackintosh, 1976; Pavlov, 1927; Prados, Alvarez, & Reynolds, 2011). Therefore, participants were presented with stimuli that were harder to distinguish from each other, in order to see if the blocking was attenuated or not relative to Experiments 2.1 or 2.2. In the present experiment all stimuli were the same shape and colour (white circles with black outline) and they all had a distinct black complex line pattern within the circle (see Figure 2.9 below).

A further investigation of temporal learning was also conducted. To test whether participants could more accurately predict the durations, a timescale was added to the Likert scale. In the timing test of Experiment 2.2 participants scored durations on a Likert scale ranging from one to nine. In Experiment 2.3 in Group NU (no units), the duration test was identical to Experiment 2.2. In Group WU (with units) time units were added to the duration test time scale indicating '- 0.5 s' next to the one on the scale and '+ 0.5 s' next to the nine on the scale. In other words, the time scale indicated how many seconds difference there were between the extremes on the Likert scale. In Experiment 2.3, it was predicted that participants would over-estimate durations, as previous research has shown that more complex stimuli durations are overestimated (Zakay & Block, 1997).

2.5.1   Methods

Participants

Twenty seven people took part in this experiment; there were 19 females and eight males. The participants were subdivided randomly into two groups; Group WU (N=13) and Group NU (N=14). Their ages ranged from 18 to 66 years ($M = 34.44$, $SD = 13.47$). Participants were mainly Psychology, Medicine and Dentistry students at Newcastle University recruited via an online volunteer scheme or in the computer cluster in the Newcastle Medical School and were all paid four pounds as a thank you.

Stimuli

Eight different cues were used; they were white with a black unique pattern (see Figure 2.13b). When the cues were inactive they were black circles (see Figure 2.13a), when they were active they were white with a black pattern. The USs were the same as

in the previous experiments. The stimuli were presented for the same time duration as the previous experiments described in this chapter (1900 ms).
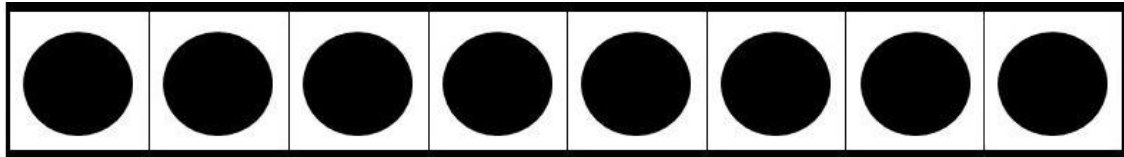
Figure 2.13a. The different cues presented on screen when they were not active.
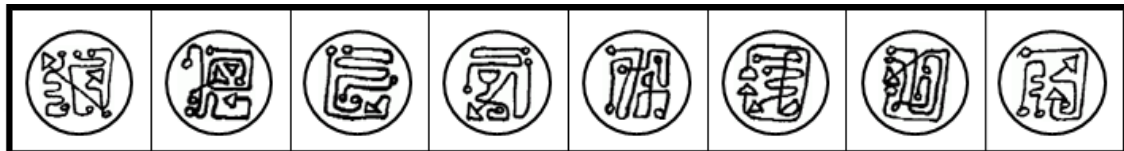
Figure 2.13b. The different cues with their respective symbols when they were active.

Procedure

These were identical to Experiment 2.2.

Training

As in the previous experiments, participants were first shown contours of the inactive buttons; i.e. when the magician had not pressed anything (in this case, they were black). The magician then pressed one or two buttons, and they would become white with a black pattern. A maximum of two buttons could be pressed at one time. The buttons remained white (CS) for 1900 ms, after which they turned completely black again.

Timing Test

The same duration test was used as in Experiment 2.2 for Group NU. However, there was extra information on the prediction slide for Group WU; a time unit was added to labels on the Likert scale so participants had a temporal reference point. The labels were: 'shorter, - 0.5 sec' next to one, 'duration the same' next to five and 'longer, + 0.5 sec' next to nine. The rest of the timing experiment was the same as the previous experiment.

2.5.2 Results

Elemental Phase

The causality ratings were submitted to a two Cue (B and N) x six Trial (1- 6) within-subjects analysis of variance (ANOVA) with both Cue and Trial as repeated measures. There was a significant difference between causality ratings for the blocking cue and the negative control when comparing ratings across trials ($F(1, 25) = 3560.59$, $p < 0.001$) in the elemental phase, see Figure 2.14. There was no difference in ratings between Group NU and WU ($F < 1$). Participants learned across trials as there was a difference across trials in causality ratings for the blocking cue ($F(5, 125) = 31.05$, $p < 0.001$) and there was no difference between causality ratings for the negative across trials ($F(5, 125) = 1.08$, $p = 0.38$).
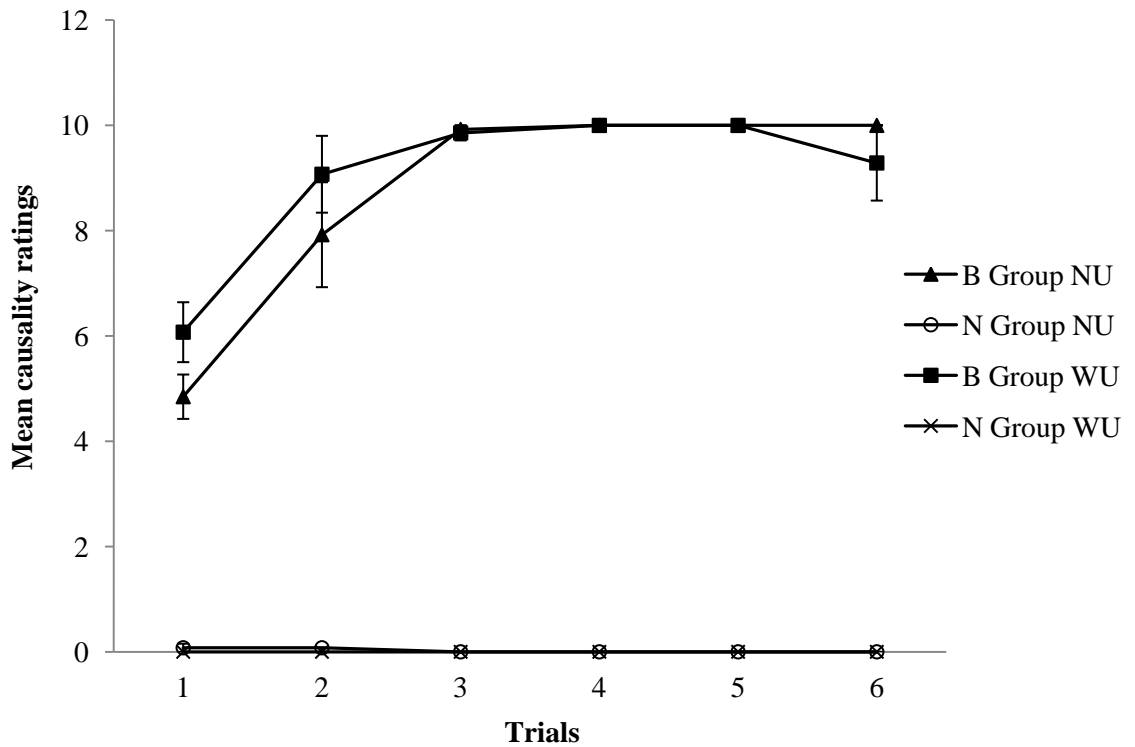
Figure 2.14. Mean causality ratings for blocking cue (B) and negative control (N) in elemental phase. Error bars show ±1 *SEM*.

Blocking

Both groups failed to show blocking; Group NU: $t(11) = 1.66$, $p = 0.12$, Group WU: $t(10) = 0.40$, $p = 0.70$. There was no difference between the blocking scores of the two groups ($t(21)= 0.81$, $p = 0.42$), see Figure 2.15.
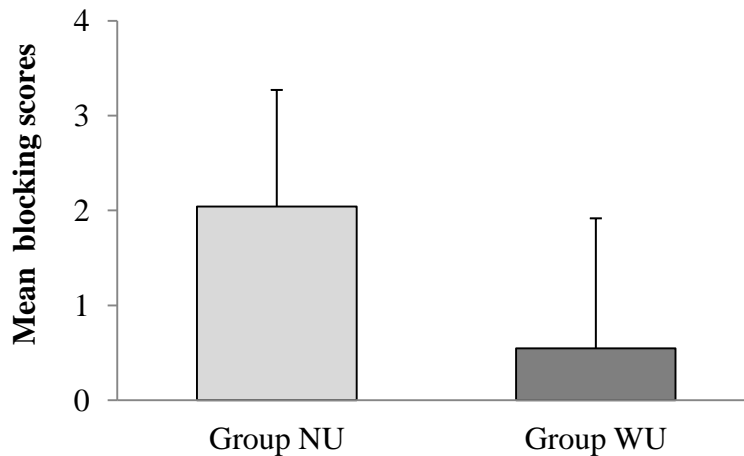
Figure 2.15. Mean blocking scores Experiment 2.3 for Group NU and Group WU. Error bars show +1 *SEM*.

Timing

Overshadowing cues

Means for temporal estimates were similar to five for the two compound overshadowing control cues; Group NU: first overshadowing cue (O1) $t(11) = 2.12$, $p = 0.06$ and second overshadowing cue (O2) $t(11) = 2.13$, $p = 0.06$ for Group WU: O1 $t(11) = 1.58$, $p = 0.14$ and O2 $t(10) = 1.44$, $p = 0.18$.

The temporal estimates were submitted to a two Cue (O1 and O2) x two Group (NU and WU) within-subjects ANOVA with both Cue and Group as repeated measures. There was no difference between estimates for target duration for overshadowing cues ($F < 1$) when comparing the two, see Figure 2.16. No main effect of Group ($F(1, 21) = 1.88$, $p = 0.18$) was observed for temporal estimates and there was also no Cue x Group interaction ($F(1,21) = 1.90$, $p = 0.18$) Therefore, the amount of information available to participants on the time scale did not influence temporal estimates for the overshadowing cues.
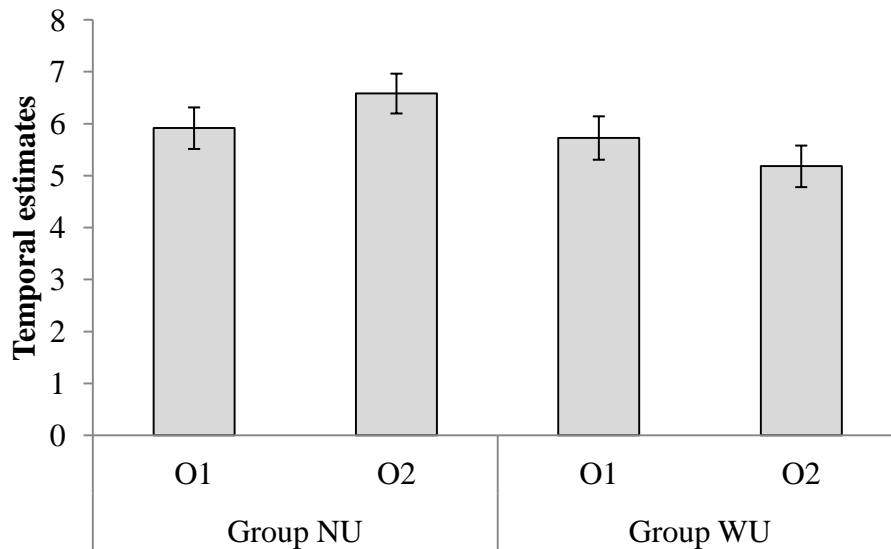
Figure 2.16. Temporal estimates for target duration for Group NU and Group WU for the two compound overshadowing control cues (O1 and O2). Error bars show ±1 *SEM*.

Blocking & target cues

The temporal estimates were submitted to a three Duration (1400, 1900 and 2400) x two Group (NU and WU) within-subjects ANOVA with both Duration and Group as repeated measures. For the temporal estimates of the blocking cue, participants were accurate at assessing the three test durations (1400, 1900 and 2400 ms) as the temporal estimates differed (ANOVA: $F(2, 42) = 15.57$, $p < 0.001$). There was no main effect of Group ($F < 1$) and there was no Duration x Group interaction ($F < 1$) for the blocking cue.

An independent t-test indicated there was no difference in standard deviations of temporal estimates of the blocking cue between experimental groups ($t(21) = -1.58$, $p = 0.13$).

The target cue estimates were also submitted to a three Duration (1400, 1900 and 2400) x two Group (NU and WU) within-subjects ANOVA with both Duration and Group as repeated measures. The durations were accurately estimated ($F(2, 42) = 40.12$, $p < 0.001$). There was no difference in estimates when comparing groups (no main effect of Group: $F < 1$), and there was no Duration x Group interaction ($F(2, 42) = 1.51$, $p = 0.23$).

There was also no difference in standard deviations for the target cue between groups ($t(21) = -1.45$, $p = 0.16$).

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The standard deviations of temporal estimates of the blocking and target cue were also compared using an ANOVA. They were submitted to a two Cue (B and T) x two Group (NU and WU) within-subjects ANOVA with both Cue and Group as repeated measures. Standard deviations for the blocking cue and target cue were similar (when grouping all test durations) as there was no main effect of Cue ($F < 1$), no main effect of Group ($F(1, 21) = 3.02$, $p = 0.10$) and no Cue x Group interaction ($F < 1$).

A one sample t-test comparing target duration temporal estimates for blocking and target cue showed estimates for blocking cue did not differ from five ($t(22) = 1.90$, $p = 0.07$), yet the target cue estimates did differ from five ($t(22) = 3.07$, $p < 0.05$). Mean estimates and standard deviations were similar for both cues (blocking cue M: 5.83, SD: 2.08 and target cue M: 5.87, SD: 1.36).

The temporal estimates for the 1900 ms cues were also submitted to a two Cue (B and T) x two Group (NU and WU) within-subjects ANOVA with both Cue and Group as repeated measures. There was also no difference between target duration estimates for blocking and target cue ($F < 1$), no main effect of Group ($F < 1$) and no Cue x Group interaction ($F < 1$).

To summarize, there was no difference in temporal estimates between groups. Therefore, the addition of time units on the Likert scale did not influence estimates. Participants were accurate at assessing the duration of the blocking cue; however, they overestimated the target cue duration.

2.5.3   Discussion

Experiment 2.3 showed an attenuation of blocking and might have been a consequence of the set of stimuli used in Experiment 2.3. Participants were probably not able to remember the stimuli and distinguish between them. One participant reported they did not realise the stimuli had different patterns on them after completing the experiment. Other participants stated they memorised the stimulus location to be able to make a prediction and they did not pay much attention to the patterns on the stimuli.

We expected temporal estimates to be more accurate in Group WU as this group had additional information concerning the time scale indicating milliseconds next to the Likert scale labels ('longer', 'actual' and 'shorter') however, there was no difference between temporal estimates between Group NU and WU. As there was no difference in temporal estimates for the two groups, in all following experiments we presented participants with Likert scales without any millisecond time indications.

Participants were not accurate at estimating the target cue 1900 ms duration, which was unexpected. As the stimuli were more complex, we expected participants would over-estimate durations (Zakay & Block, 1997) in both groups for all the stimuli; however, this was not the case. Therefore, the more complex stimuli did not influence accuracy of temporal estimates. The results therefore partly support SET (Gibbon, 1991), as the SET would predict (as in Experiment 2.2) that the temporal estimates would not differ between cues with identical modalities and durations. When comparing temporal estimates directly, the estimates did not differ; however, participants were not accurate at estimating the target cues when comparing estimates to predicted ratings.

2.6   General discussion

The procedures for the experiments described above is similar to previous human learning experiments and showed comparable results (Boddez et al., 2011; De Houwer & Beckers, 2003; De Houwer et al., 2002). It is clear from Experiment 2.3 that blocking can be influenced by changing stimulus properties, i.e. by making them more difficult to distinguish (e.g. Honig, 1981; Livesey & McLaren, 2009). The following chapters will look at changes in cue properties, importance of stimulus properties on cue competition and how cue properties influence blocking and overshadowing.

The above experiments also showed that the duration test was a good way of assessing temporal estimates. This method of testing was chosen as this gives us the opportunity to look at estimates for different durations and more easily compare data between cues and test durations. Usually, participants' ability to remember durations or time intervals is tested by presenting participants with an auditory target cue duration, and following this, presenting participants with two cues; one with a target duration and one with a different duration, and asking them if they are the target duration, giving participants a yes/ no response option (Ogden, Wearden, & Jones, 2010; Wearden & Grindrod, 2003). This typical duration test is not a viable option for associative learning experiments, as testing temporal estimates throughout training would disrupt associative learning. For example, a typical duration test setup would have required cues to only have been presented individually, and not in compound. Therefore, the duration test was conducted after participants had made causal predictions but was still broadly speaking compatible with timing experiments.

From the above experiments it can be concluded that cue durations were accurately assessed. The experiments in the following chapters tested whether changes

in stimulus properties, duration and relative cue location also changed duration estimates of stimuli. This novel information about temporal estimates of stimuli in cue competition experiments could shed light on whether durations are encoded as part of associations (e.g. Balsam & Gallistel, 2009; Honig, 1981; Savastano & Miller, 1998).

Chapter 3. Stimulus colour and shape do not enhance blocking or overshadowing

3.1 Introduction

Previous research has shown that various stimulus properties, such as shape, colour, size and location, influence cue competition (Alexander, Wilson, & Wilson, 2009; Prados, 2011) as these characteristics make stimuli unique and recognisable. For example, cue colour has been shown to influence cue competition (Graham, Good, McGregor, & Pearce, 2006). Colour is widely used for recognising objects (Mollon, 1989) such as food and prey (Osorio & Vorobyev, 2008) and removing some of the colour information in cues changes overt attention participants pay to them (Frey et al., 2011). Graham et al. (2006) found that cue colours influenced learning in rats. In their spatial experiments rats had to swim to a platform in a pool. When the walls surrounding the pool were painted in different colours, this enhanced learning about the shape of the pool. Cue colour may have given rise to enhanced learning about the cue, as colour is a very distinct cue property (Derrington et al., 2002).

Another factor that might influence associative learning and cue competition is the experimental instructions participants receive. Instructions have been shown to influence the way participants learn about stimuli (Baetu & Baker, 2010; De Houwer, 2009; Lipp, Neumann, & Mason, 2001; Melchers, Shanks, & Lachnit, 2008; Williams et al., 1994). Mitchell and Lovibond (2002) found that instructions influenced blocking in human causal learning experiments. When participants were presented with additivity instructions, blocking was observed, whilst when additivity instructions were excluded, blocking was absent. In Williams et al. (1994) there was a difference in blocking in the group which had categorical instructions compared to the non- categorical instructions group. Namely, blocking was observed in the category group, whilst no blocking was observed in the non-category group.

Previous studies have shown that similarity of cues or number of shared cue elements causes generalization in causality judgements of cues (Pearce, 1987), which can affect associative strength (Amundson & Miller, 2008). The generalization theory predicts that participants will generalize CRs for cues that are more similar (Pearce, 1987, 1994). Thus, if cues share more elements in one group than another group, a greater generalization should be observed in the group in which more elements are

shared (Pearce, 1987, 1994), and blocking should be weaker because causality ratings are generalized between cues.

Cue saliency may also influence cue competition as previous research has shown cue colour effects cue competition (Graham et al., 2006). The cue colour may determine the saliency of a cue, which in turn influences the amount of attention participants pay to cues, which in turn effects cue competition (Mackintosh, 1975b; Pearce & Hall, 1980). Most associative learning theories make predictions about how much attention is paid to CSs and USs (Mackintosh, 1975b; Pearce & Hall, 1980) to be able to predict the associative strength between stimuli. Attention in this circumstance is defined as thinking about or processing the stimulus. Therefore, saliency can influence associative learning as participants might pay more attention to a cue that is more salient. For example, when cues have a greater biological significance they are more salient (Denniston, Miller & Matute, 1996).

The Rescorla and Wagner (1972) model states that saliency of cues is important as learning about the relationship between CS and US depends on stimulus salience. Rescorla and Wagner (1972) predicted that associative strength of stimuli depends on stimulus interaction; learning about a cue depends on the history and the magnitude of the US. Therefore, stimulus saliency may affect stimulus interaction whereby cues that share common elements might be more difficult to discriminate leading to generalization (Pearce 1987) and an attenuation of any cue competition effect.

Cue properties may also influence cue competition as they change perception of cue context, which has been shown to influence human predictive learning (Le Pelley, Oakeshott, Wills, et al., 2005; Leon, Abad, & Rosas, 2011; Rosas & Callejas-Aguilera, 2006). For example, when the outcome context is different from one trial to the next but the cues remain the same, participants see this as two different sets of cues or stimuli (Le Pelley, Oakeshott, Wills, et al., 2005). Similarly, if the location of a stimulus changes, a context effect might occur, i.e. that every time a stimulus changes location, participants think it is a different stimulus. In a study by Dibbets, Maes, and Vossen (2000) when stimuli did not have a set location, blocking was attenuated. Dibbets et al. (2000) assumed that participants were remembering the cues (and so the stimuli) by their location, and when location was not fixed, people could not remember the cues and so blocking was attenuated. Another explanation for this could be that participants perceive the cue as moving around from one cue location to the next. Therefore, cue location is an important factor in mediating cue competition effects (see Dibbets et al., 2000).

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Previous research (Dibbets et al., 2000) indicates that blocking and overshadowing is attenuated when cues do not have a set location. The following experiments looked at whether different stimulus properties such as location, shape and colour affected blocking and overshadowing. Due to previous research, it was predicted that blocking and overshadowing would be attenuated when cues did not have a set location (Dibbets et al., 2000).

Previous studies have shown that when a cue is physically moving, participants overestimate cue duration (Aubry, Guillaume, Mogicato, Bergeret, & Celsis, 2008; Brown, 1995). Fraisse (1984) suggested that this happens because people's estimation of time is affected by changes in experimental setup (i.e. cue appearance or location) that occur during a task and the amount of attention that is paid to the task. Mate, Pires, Campoy, and Estaun (2009) showed that when the cues were static and the background moved this influenced the temporal estimates of the cue. Mate et al. (2009) suggested that by moving the background, a level of complexity was added to the cues which could change temporal estimates. The added complexity could also influence causality ratings, especially if associations and timing are encoded simultaneously (Balsam & Gallistel, 2009).

In order to determine the relationship between learning and timing, the experiments in this chapter set out to test whether temporal estimates were influenced by cue properties. Several predictions about temporal estimates could be made. Firstly, it was predicted that there would be a greater variance in temporal estimates when cues did not have a set location, as participants would not be able to remember the cues as these are remembered by location only (Dibbets et al., 2000). However, a second possibility was that duration would be overestimated, as cues without a set location could be perceived as moving (Fraisse, 1984). A third prediction could be made in accordance with the SET model (Gibbon, 1991), namely that temporal estimates and variance in the data would be similar for all cues as modality did not vary between groups.

3.2 Experiment 3.1

This chapter addressed the influence of cue location and other aspects of cues on cue competition using the magician paradigm (as described in Chapter 2). Experiment 2.3 showed that black and white cues that were very similar were hard to distinguish, thus blocking was attenuated. The present experiment was conducted to investigate if

there was a difference in blocking when visual properties of cues differed. Hence, in this experiment one set of cues were coloured squares and the second set of cues consisted of black and white patterned squares. In groups in which cues were black and white with patterns, blocking was predicted to be attenuated because cues were more similar (all same colour). Furthermore, colour is salient cue property (Derrington et al., 2002) and attenuation of blocking was found in Experiment 2.3 when cues were also black and white, thus this is also why blocking was expected to be attenuated in the black and white cue group.

Dibbets et al. (2000) ran two experiments in which the position of the cues was randomised during training; one using fictional stock names and a second using geometrical cues instead of names. Dibbets et al. (2000) found attenuated blocking when locations of cues were randomised during training. Thus, in Experiment 3.1 we tested four groups; two groups in which cues had a set location during training, and two groups in which cues were presented at a random location. For the non-set location group the experiment was programmed to show any cue at three possible locations in the row of lightning machine buttons during training and testing. Two compound stimuli were always shown with one empty button between them.

To test influence of visual cue type and location of stimulus, four groups were tested in this experiment. As stated above, two groups had cues with a fixed location, namely Group C-FL in which cues were coloured squares and Group P-FL in which cues were black and white with patterns. In the other two groups cues did not have a set location, Group C-NFL had coloured squares and P-NFL had black and white patterned cues.

It was predicted that blocking would not be observed in groups in which cues did not have a fixed location (C-NFL and P-NFL), whilst blocking was expected in groups in which cues had a fixed location (C-FL and P-FL). Also, it was predicted that blocking would be greater in groups in which coloured cues rather than black and white cues were shown to participants. In other words, blocking scores would be higher in Group C-FL than group P-FL. It was also predicted that cue duration would be overestimated in groups in which cues had random locations compared to temporal estimates of cues in groups in which cues had set locations throughout training and testing. It was expected that there would be no difference in temporal estimates between groups with coloured and black and white cues.

3.2.1 Method

Participants

Forty one participants took part in this study (28 female and 13 male). Ages ranged from 19 to 62 ($M = 29.80$, $SD = 11.44$). Participants were Newcastle University undergraduates or members of the public who had volunteered by registering for the Institute of Neuroscience volunteer scheme. Psychology students got research credit for taking part and other volunteers were paid four pounds as a thank you.

Stimuli

For this experiment two sets of square shaped cues (CSs) were used. One set had cues which were all a different colour, while the second set had cues which all had a different black and white pattern. Apart from the cues, the setup of the experiment was identical to the previous experiment, Experiment 2.3.

Procedure

The training schedule for Experiment 3.1 was identical to Experiment 2.3. There were four conditions in this experiment; C-FL, P-FL, C-NFL and P-NFL. Participants were randomly assigned to each group with eleven participants in Group C-FL and ten participants in Groups P-FL, C-NFL and P-NFL. The instructions for the experiment were identical to Experiment 2.3 except when participants were informed about the appearance (visual properties) of the buttons. For Groups C-FL and C-NFL the instructions specified that 'lit' buttons would be coloured, and in Groups P-FL and P-NFL instructions reported that 'a distinct pattern' would appear on buttons that were lit. Participants for all four groups received the same information about location of cues; instructions explained that the magician was not sure whether the buttons were in the most suitable position so he might swap them around from time to time. Thus, participants were explicitly instructed to pay attention to colour or pattern on the button (depending on the group).

3.2.2 Results

Blocking

Groups in which cue location varied from trial to trial did not show blocking; Group C-NFL: $t(9) = 1.79$, $p = 0.11$ and Group P-NFL: $t(9) = 1.01$, $p = 0.34$. However, the two groups in which cues had a fixed location throughout training and testing did show blocking; Group C-FL: $t(10) = 12.49$, $p < 0.001$ and Group P-FL: $t(9) = 5.95$, $p < 0.001$, see Figure 3.1.

The blocking scores were submitted to a four Group (C-FL, C-NFL, P-FL and P-NFL) between-subjects ANOVA with Groups as between subjects factors. There was a difference between blocking scores when comparing mean blocking scores between groups; $F(3, 37) = 7.83$, $p < 0.001$.

When comparing blocking scores for different factors (colour and location) there was a difference between blocking scores in groups in which cues had set locations to conditions in which cues did not have a set location; $t(39) = 4.56$, $p < 0.001$. There was no difference between blocking scores for groups with coloured compared to black and white patterned cues; $t(39) = 1.24$, $p = 0.22$. In other words, there was an effect of location on blocking scores.
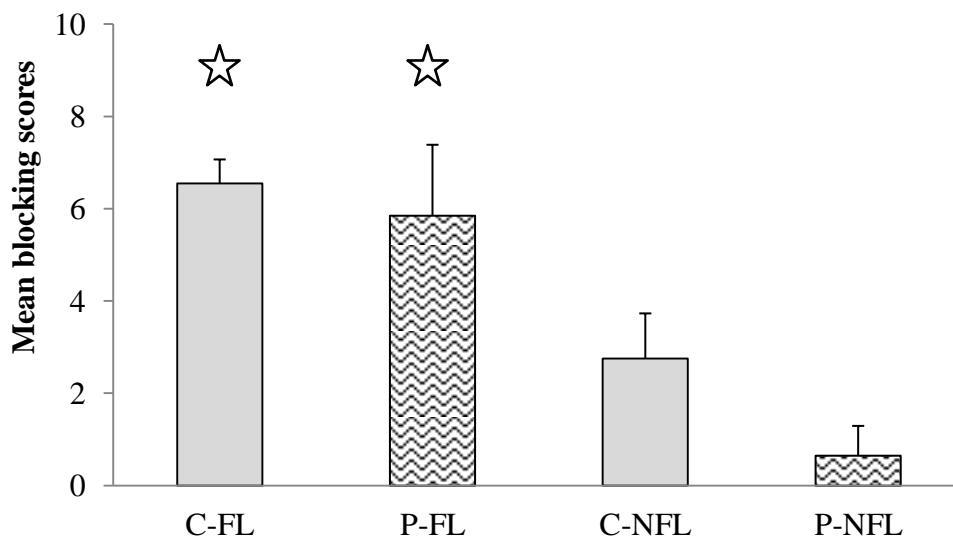
Figure 3.1. Mean blocking scores for the different Groups (C-FL, P-FL, C-NFL and P-NFL). Error bars show +1 *SEM*. A star indicates significant blocking.

Temporal estimation

Overshadowing & control cues

The mean temporal estimates for the overshadowing cues were similar, see Figure 3.2. The temporal estimates were submitted to a two Cue (O1 and O2) x four Group (C-FL, C-NFL, P-FL and P-NFL) within-subjects ANOVA with Cues and Groups as repeated measures. There was no main effect of Cue ($F(1, 21) = 3.48, p = 0.07$) and there was no difference in mean temporal estimates when comparing overshadowing scores in different groups ($F(3, 21) = 1.21, p = 0.33$). There was also no Cue x Group interaction ($F(3, 21) = 1.29, p = 0.31$).

When comparing cues that were in groups with coloured cues and cues in groups with black and white cues (with Cues and Groups with Coloured Cues as repeated measures), there was no difference between temporal estimates ($F(1, 21) = 1.32, p = 0.26$). When comparing groups in which cue location (with Cue and Groups with Fixed Location as repeated measures) was set compared to those in which location was not fixed, there was also no difference between estimates ($F < 1$).
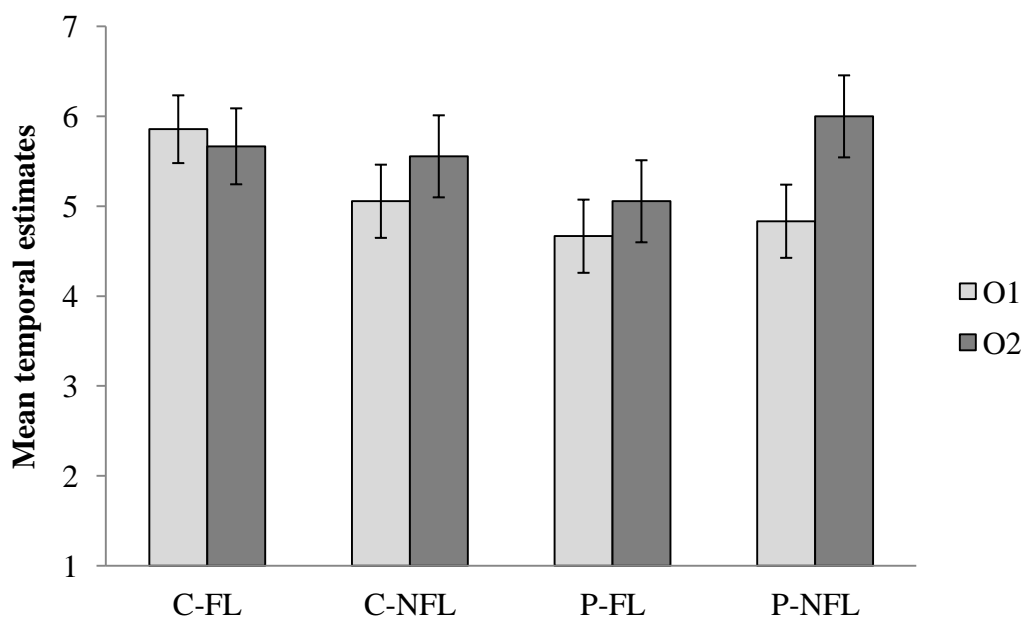
Figure 3.2. Mean temporal estimates for overshadowing cues across Groups (C-FL, P-FL, C-NFL and P-NFL). Error bars show ±1 *SEM*.

Temporal estimates for the target duration were very similar for the two overshadowing cues across groups, see Table 3.1. The 1900 ms duration temporal estimates were submitted to a two Cue (O1 and O2) x four Group (C-FL, C-NFL, P-FL

and P-NFL) within-subjects ANOVA with Cues and Groups as repeated measures. The temporal estimates for the target duration did not differ between the two overshadowing cues (Cue: $F < 1$) and there was no Group x Cue interaction ($F < 1$). There was also no difference when comparing the temporal estimates of the overshadowing cues between groups (Group: $F < 1$).

An ANOVA was also conducted with Cue and Groups as repeated measures looking at factors such colour (Group C-FL and C-NFL compared to P-FL and P-NFL) there was no difference between groups (Colour: $F < 1$) and location did not influence temporal estimates; when comparing C-FL and P-FL to C-NFL and P-NFL temporal estimates there was no difference in estimates (Location: $F < 1$). Consequently, there was no effect of location or cue colour on temporal estimates for the overshadowing cues.

Table 3.1. Target duration means (*M*) and standard deviations (*SD*) for the first (O1) and second (O2) overshadowing cue per group (Gr).

	O1					O2			
Gr	*C-FL*	*C-NFL*	*P-FL*	*P-NFL*		*C-FL*	*C-NFL*	*P-FL*	*P-NFL*
M	5.57	5.33	4.83	5.50		5.00	5.67	4.83	6.00
SD	1.81	2.58	2.56	1.64		2.16	1.21	2.56	2.10

Blocking & target cue

The temporal estimates for the blocking cue were submitted to a three Duration (1400, 1900 and 2400 ms) x four Group (C-FL, C-NFL, P-FL and P-NFL) within-subjects ANOVA with Duration and Groups as repeated measures. There was a difference between temporal estimates for the test durations for the blocking cue ($F(2, 42) = 20.79$, $p < 0.001$). When comparing temporal estimates across the four groups, there was no difference in temporal estimates for the blocking cue ($F(3, 21) = 1.56$, $p = 0.23$). A Group x Duration interaction ($F(6, 42) = 2.57$, $p = 0.03$) was found, see Figure 3.3.
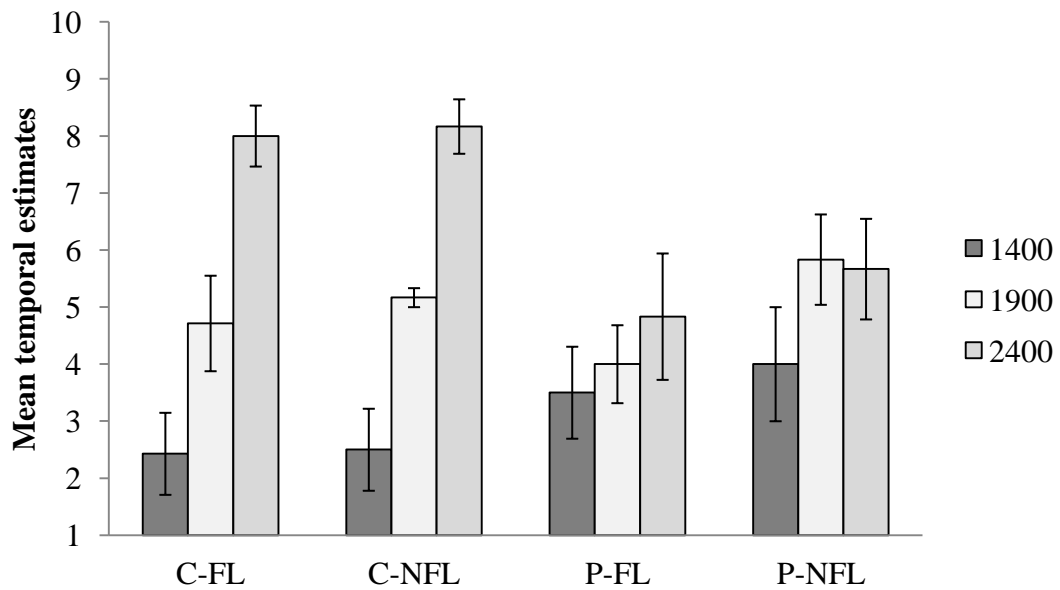
Figure 3.3. Mean temporal estimates for blocking cue per group (C-FL, P-FL, C-NFL and P-NFL) and duration (in ms). Error bars show ±1 *SEM*.

A between subjects ANOVA with Colour (Coloured and Patterned Cues) and Location (Fixed and Not Fixed Location) as between subjects factors was conducted to look at this in more detail. The ANOVA did not show an effect of colour on estimates for temporal estimates for the shorter duration ($F(1, 21) = 2.49$, $p = 0.13$), no effect on the target duration ($F < 1$), however, for the longer duration there was an effect of colour ($F(1, 21) = 13.28$, $p < 0.01$). The longer duration estimates were higher in the colour cue groups than in the pattern group.

When looking at blocking cue temporal estimates for the three test durations and analysing all three durations in an ANOVA with Colour and Location as between subjects factors there was no main effect of Colour ($F(1, 21) = 1.55$, $p = 0.23$) or Location ($F(1, 21) = 2.33$, $p = 0.14$). To conclude, the temporal estimates for the blocking cue were slightly influenced by colour of the cues.

The temporal estimates for target cue were submitted to a three Duration (1400, 1900 and 2400 ms) x four Group (C-FL, C-NFL, P-FL and P-NFL) within-subjects ANOVA with Duration and Groups as repeated measures. The target cue temporal estimates were accurate for each duration as estimates differed between test durations (Greenhouse Geisser: $F(1.55, 32.64) = 26.66$, $p < 0.001$). There was no Group x Duration interaction for the target cue estimates ($F(4.66, 32.64) = 1.50$, $p = 0.22$) and there was no difference in estimates between groups (main effect of Group: $F < 1$), see Figure 3.4.
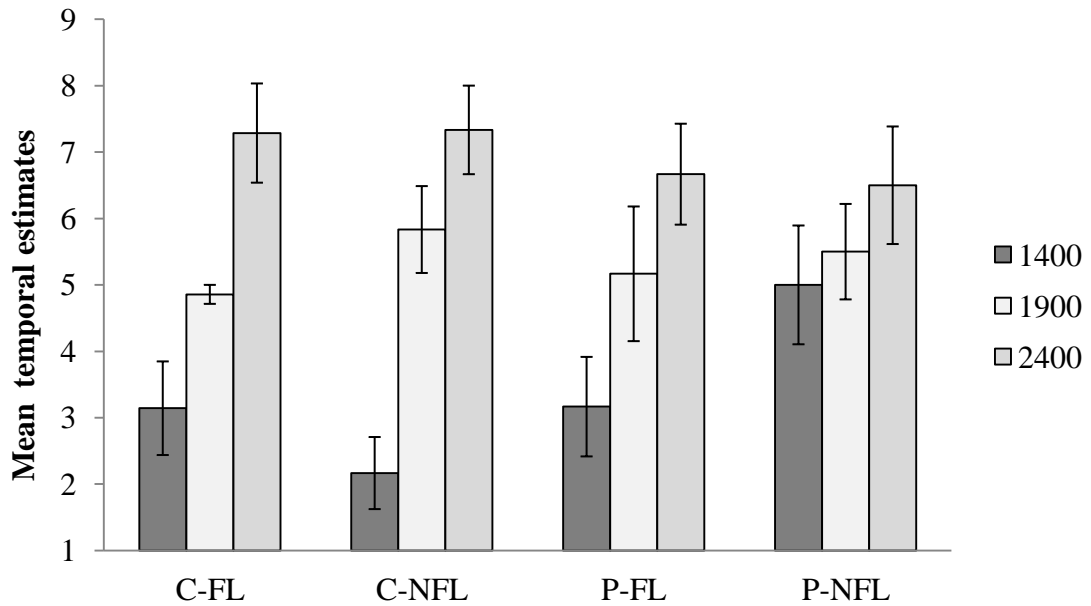
Figure 3.4. Mean temporal estimates for target cue per group (C-FL, P-FL, C-NFL and P-NFL) and duration (in ms). Error bars show ±1 *SEM*.

When conducting an ANOVA on target cue standard deviation temporal estimates with Duration and different factors Colour and Location as repeated measures there was also no main effect of Colour ($F < 1$) or Location ($F < 1$). Therefore, colour and location did not influence temporal estimates for the target cue.

The temporal estimates were submitted to a two Cue (B and T) x four Group (C-FL, C-NFL, P-FL and P-NFL) within-subjects ANOVA with Cues and Groups as repeated measures. When comparing standard deviations for blocking and target cue for the mean temporal estimates, there was no main effect of Group ($F(3, 21) = 1.63$, $p = 0.21$). However, there was a main effect of Colour ($F(1, 21) = 4.50$, $p = 0.05$), see Figure 3.5. For the standard deviations the Cue and Groups with different factors as repeated measures were also analysed. Standard deviations were higher in the groups in which cues had different colours compared to the groups in which cues were black and white (patterns). There was no main effect of Location ($F < 1$) and there was no Colour x Location interaction ($F < 1$).
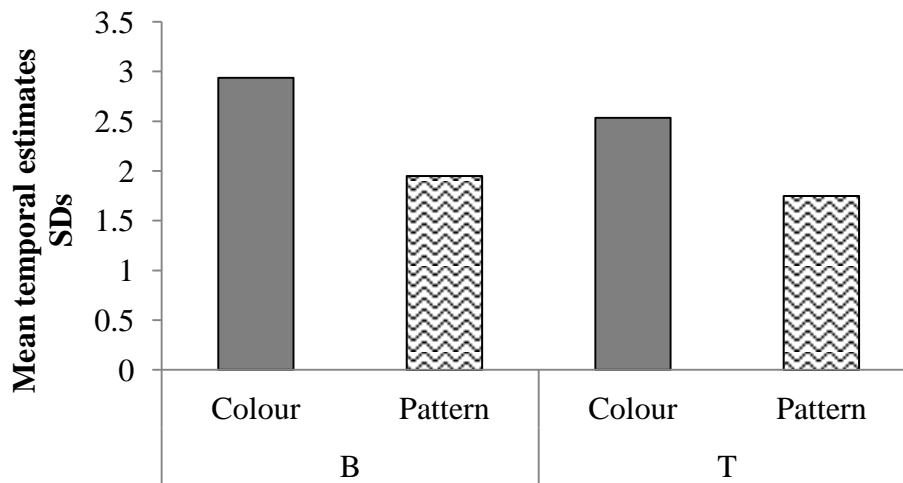
Figure 3.5. Mean standard deviations for temporal estimates for blocking cue (B) and target cue (T) for Colour (Groups C-FL and C-NFL) and Pattern (Groups P-FL and P-NFL). Error bars show ±1 *SEM*.

Both blocking and target cue temporal estimates for the target duration were accurate, as both estimates did not differ from five (blocking cue $t(24) = -0.23$, $p = 0.82$ and target cue: $t(24) = 0.98$, $p = 0.34$).

The 1900 ms temporal estimates were submitted to a two Cue (O1 and O2) x four Group (C-FL, C-NFL, P-FL and P-NFL) within-subjects ANOVA with Cues and Groups as repeated measures. When comparing blocking and target cue estimates for the target duration there was no main effect of Cue ($F < 1$), no effect of Group ($F(3, 21) = 1.04$, $p = 0.40$) and no Cue x Group interaction ($F < 1$). Therefore, there was no difference between temporal estimates of the blocking and target cue.

3.2.3   *Discussion*

There was no difference in blocking scores between groups with black and white or coloured cues. Therefore, the prediction that coloured cues would be discriminated more easily was not confirmed. Location did effect blocking, as groups in which cue location was not fixed showed attenuated blocking. The temporal estimate results showed that participants were slightly influenced by the colour of the cues as for the longer duration participants underestimated the duration of the blocking cue in groups in which the cues were black and white. Participants also showed more variation in estimates in the different cue colour groups; this could be because participants entered a larger range of scores (including the correct higher scores) for the coloured cues than the black and white cues. However, this was not reflected in the mean estimates as they

did not differ between groups for the different factors (colour and location) for the blocking and target cue. Participants gave similar estimates for the blocking and target cue; i.e. there was no difference in estimates between the two cues. To conclude, the blocking scores were influenced by location yet temporal estimates were only slightly influenced by cue colour.

Most theories about blocking and associative learning explain cue competition effects in terms of individual or pairs of cues, i.e. not a collection of cues presented during training (Kamin, 1969; Mackintosh, 1975b; Pearce & Hall, 1980; Rescorla & Wagner, 1972) . In other words, individual cues could be responsible for blocking or overshadowing. Kamin (1969) predicted blocking would occur when one cue, the blocking cue, stops an association forming about a second cue, the target cue. Therefore, according to Kamin, blocking solely depends on those two cues. Rescorla and Wagner (1972) hypothesised that associative strength is influenced by all cues present in a trial. In the experiment described above all stimuli in the experiment had a set location, or all of the stimuli did not. Therefore, nothing could be said about which or how many individual stimuli were influencing blocking. Thus, another experiment was run in which particular stimuli did not have a set location so that the influence of individual stimuli could be tested.

3.3   Experiment 3.2

In the previous experiment blocking was attenuated when cues did not have a set location, yet, the experiment did not test whether specific cues were responsible for attenuation of blocking. Therefore, the following experiment was set up to examine whether blocking was also attenuated when only one cue did not have a set location, namely the blocking or the target cue. Four groups were tested in this experiment. The first group was All-FL in which all cues had a fixed location. In group B-NFL, the blocking cue did not have a fixed location. The third condition, T-NFL, was programmed to show target cue at a random location throughout training and testing. In the last condition, All-NFL, all the cues did not have a fixed location, except compound control stimuli C1 and C2. Kamin (1969) hypothesised that one cue could be responsible for blocking (i.e. that not all cues in a present trial influenced blocking), therefore it was predicted that when the target or blocking cue did not have a fixed location, blocking would be attenuated. As mostly there were no differences in temporal estimates between groups or individual stimuli in the previous experiment, temporal

estimates were expected to be similar for cues and between groups in this experiment, which is in line with the SET model (Gibbon, 1991).

3.3.1 Method

Participants

Fifty five participants took part in this study in total; however two volunteers were excluded from the cue competition analysis because they did not give causality ratings for all the stimuli. Ten volunteers were male and 43 were female and age ranged from 18 to 28 ($M = 20.04$, $SD = 2.52$). Three participants were non-native English speakers, and 50 were English mother tongue speakers. Participants were Newcastle University undergraduates or members of the public. Psychology students were given research credit for volunteering- other participants were paid four pounds as a thank you.

Stimuli

The same cues were used in this experiment as in Experiment 3.1; they were coloured squares.

Procedure

Participants were randomly allocated to each group; there were 12 participants in Group B-FL, 13 in Group All-FL and T-NFL and 14 in Group All-NFL.

3.3.2 Results

Blocking

Blocking was observed in the three groups: All-FL: $t(12) = 8.90$, $p < 0.001$; B-NFL: $t(12) = 3.95$, $p < 0.01$; T-NFL: $t(12) = 4.28$, $p < 0.01$. However, when most cues did not have a fixed location, except the two control cues, blocking was attenuated: All-NFL: $t(13) = 1.97$, $p = 0.07$, but did approach significance (see Figure 3.6).

The blocking scores were submitted to a four Group (All- FL, B-NFL, T-NFL and All-NFL) between-subjects analysis of variance (ANOVA) with Group as a between subjects factor. There was no difference when comparing blocking scores across the four groups (Group: $F(3, 49) = 2.68$, $p = 0.06$). Thus, the location of the cues, namely when all cues did not have set location, influenced blocking.

The blocking scores were also submitted to a two Factor (B fixed location or not, and T fixed location or not) between-subjects analysis of variance (ANOVA) with B or T Location Factor as a between subjects factor. There was a difference between blocking scores between groups in which the blocking cue did not have a fixed location and groups in which the blocking cue had a set location ($F(1, 49) = 6.31$, $p = 0.02$). There was no difference when comparing blocking scores in groups in which the target cue had a set location or did not have a set location ($F(1, 49) = 1.58$, $p = 0.22$). There was no interaction between groups in which the target cue had a set location and groups in which the blocking cue set location interaction (Target cue set location x blocking cue set location: $F < 1$).
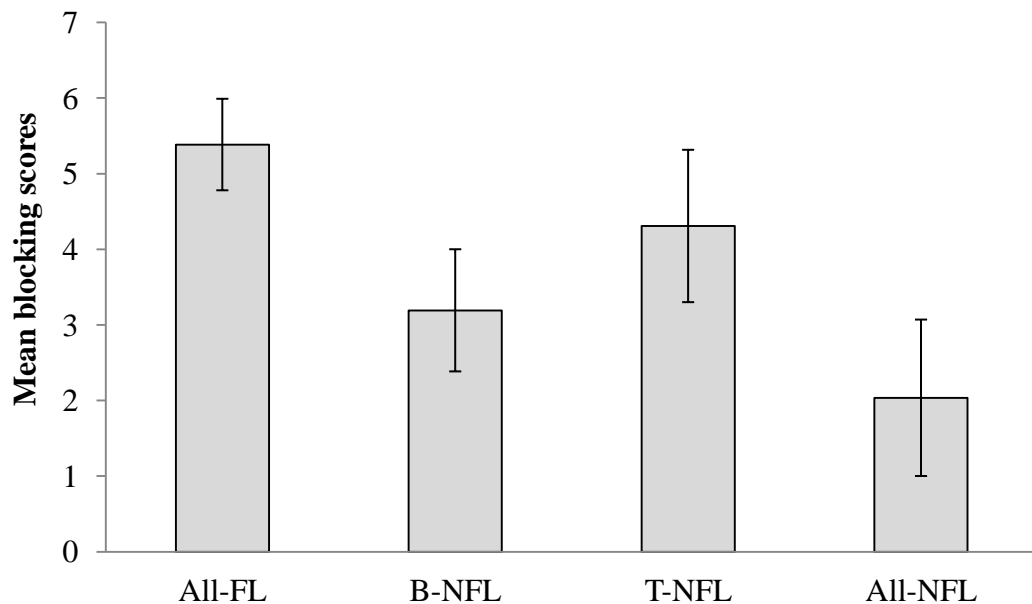
Figure 3.6. Mean blocking scores for the different groups. Group All-NFL showed attenuated blocking, in other groups blocking was significant. Error bars show ±1 *SEM*.

Temporal estimation

Overshadowing cues

Mean temporal estimates for the two overshadowing cues were similar, see Figure 3.7. The temporal estimates were submitted to a two Cue (O1 and O2) x four Group (All-FL, B-NFL, T-NFL and All-NFL) within-subjects analysis of variance (ANOVA) with both Cue and Group as repeated measures. There was no main effect of Cue ($F < 1$), no main effect of Group ($F < 1$) and no Cue x Group interaction ($F(3, 49) = 2.15$, $p = 0.11$).

An ANOVA was also conducted with a two Cue (O1 and O2) x two Factor (B fixed or not and T fixed or not) within-subjects analysis of variance (ANOVA) with both Cue and Factor as repeated measures. There was also no difference between estimates when comparing groups in which blocking cue had a set location or not ($F < 1$), or when the target cue had a set location or not ($F < 1$). There was no Blocking cue set location x Target cue set location interaction ($F(1, 49) = 1.78$, $p = 0.19$).

Standard deviations for temporal estimates for the first overshadowing cue were 2.28 and 1.91 for the second overshadowing cue. The standard deviations were also compared with an ANOVA with a two Cue (O1 and O2) x four Group (All-FL, B-NFL, T-NFL and All-NFL) within-subjects analysis of variance (ANOVA) with both Cue and Group as repeated measures. When comparing standard deviations there was a main effect of Cue ($F(1, 49) = 6.34$, $p = 0.02$), but there was no difference between groups ($F < 1$) and no interaction ($F(3, 49) = 1.35$, $p = 0.27$).
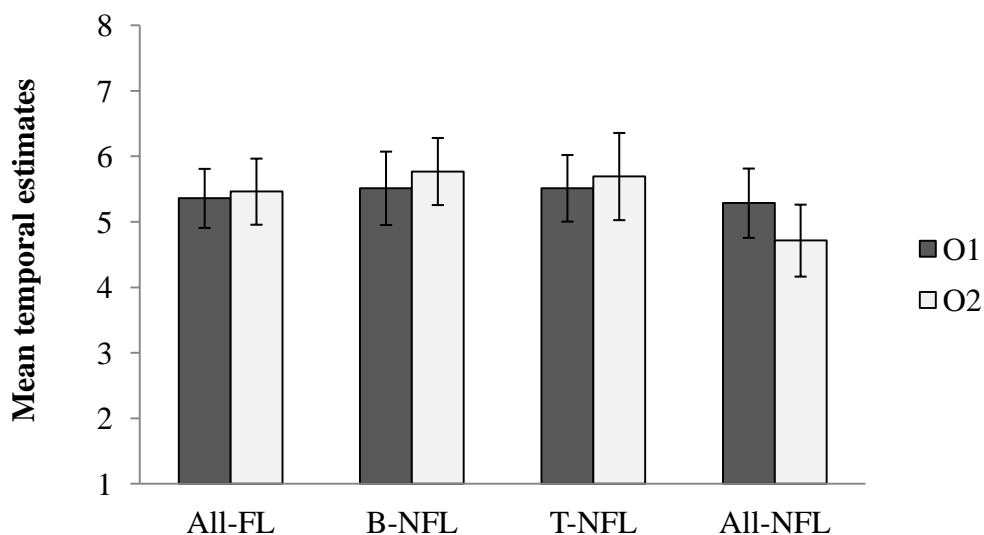
Figure 3.7. Mean temporal estimates per group for first (O1) and second (O2) overshadowing cue. Error bars show +1 *SEM*.

Blocking & target cue

To compare the temporal estimates of the blocking cue for the three different test durations an ANOVA was conducted with a three Duration (1400, 1900 and 2400) x four Group (All-FL, B-NFL, T-NFL and All-NFL) within-subjects analysis of variance (ANOVA) with both Duration and Group as repeated measures. There was a difference between estimates for the different durations ($F(2, 98) = 65.74$, $p < 0.001$). There was

no main effect of Group ($F(3, 49) = 1.96$, $p = 0.13$) for temporal estimates, and there was no Duration x Group interaction ($F(6, 98) = 1.93$, $p = 0.08$).

Another ANOVA was conducted with a three Duration (1400, 1900 and 2400) x two Factors (Blocking cue location and Target cue location) within-subjects analysis ANOVA with Duration and Factor as repeated measures. There was no difference between groups in which blocking cue had a set location or not ($F < 1$) and temporal estimates were also not influenced by the target cue not having a set location ($F < 1$). There was an interaction between the two ($F(1, 49) = 5.11$, $p = 0.03$), see Figure 3.8. To conclude, when the blocking and target cue were both in the same 'state' i.e. both set location or both no set location, the mean temporal estimate was approximately five, whilst when either one of them does not have a set location, means were slightly higher.
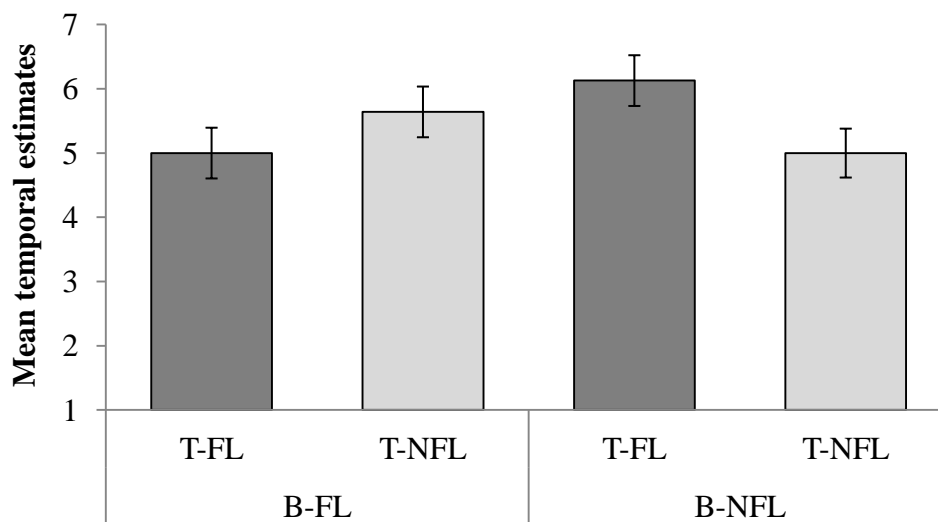
Figure 3.8. Temporal estimates for the blocking cue for the different groups; target cue fixed location (T-FL), target cue no fixed location (T-NFL), blocking cue fixed location (B-FL) and blocking cue no fixed location (B-NFL) throughout training and testing. Error bars show ±1 *SEM*.

The temporal estimates for target cues were also compared with a three Duration (1400, 1900 and 2400) x four Group (All-FL, B-NFL, T-NFL and All-NFL) within-subjects analysis of variance (ANOVA) with both Duration and Group as repeated measures. Results were similar for the target cue temporal estimates. Estimates differed between test durations (main effect of Duration: $F(2, 98) = 33.98$, $p < 0.001$). There was also a main effect of Group ($F(1, 49) = 3.05$, $p = 0.04$). Group B-NFL showed higher temporal estimates than the other groups (see Figure 3.9), and Group All-FL

slowed slightly lower estimates for all the durations. There was no Duration x Group interaction ($F < 1$).

Factors were analysed with a three Duration (1400, 1900 and 2400) x two Factors (Blocking cue location and Target cue location) within-subjects analysis ANOVA with Duration and Factor as repeated measures. There was no difference between groups in which the blocking cue did not have a set location, compared to ones in which it did ($F(1, 49) = 2.7$, $p = 0.11$) and there was no effect of target cue location ($F < 1$). There was an interaction between groups in which the blocking cue had a set location and groups in which the target cue had a set location (blocking cue set location x target cue set location: $F(1, 49) = 6.34$, $p = 0.02$).
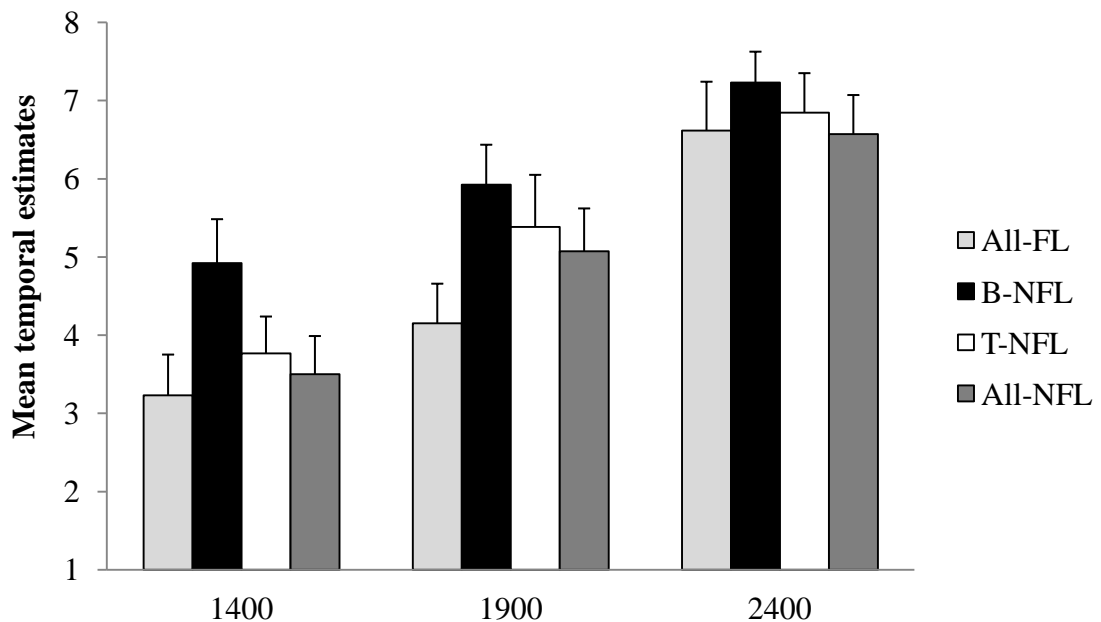
Figure 3.9. Mean estimates for the blocking cue for the different groups. Error bars show ±1 *SEM*.

Target duration (1900 ms) temporal estimates were compared with a two Cue (B and T) x four Groups (All-FL, B-NFL, T-NFL and All-NFL) within-subjects analysis ANOVA with Cue and Group as repeated measures. The estimates for the target duration were compared for blocking and target cue. There was no main effect of Cue ($F(1, 49) = 2.03$, $p = 0.16$), however there was a main effect of Group ($F(3, 49) = 3.45$, $p = 0.03$), see Figure 3.10. There was no Cue x Group interaction ($F(3, 49) = 1.19$, $p = 0.32$).

A similar ANOVA was conducted to compare factors; a two Cue (B and T) x two Factor (B cue location and T cue location) within-subjects analysis ANOVA with

Cue and Factor as repeated measures. Whether the blocking cue had set location or not throughout training and testing did not influence duration estimates ($F(1, 49) = 3.21$, $p = 0.08$) and neither did the location of the target cue ($F < 1$). There was an interaction between the two ($F(1, 49) = 6.30$, $p = 0.02$).
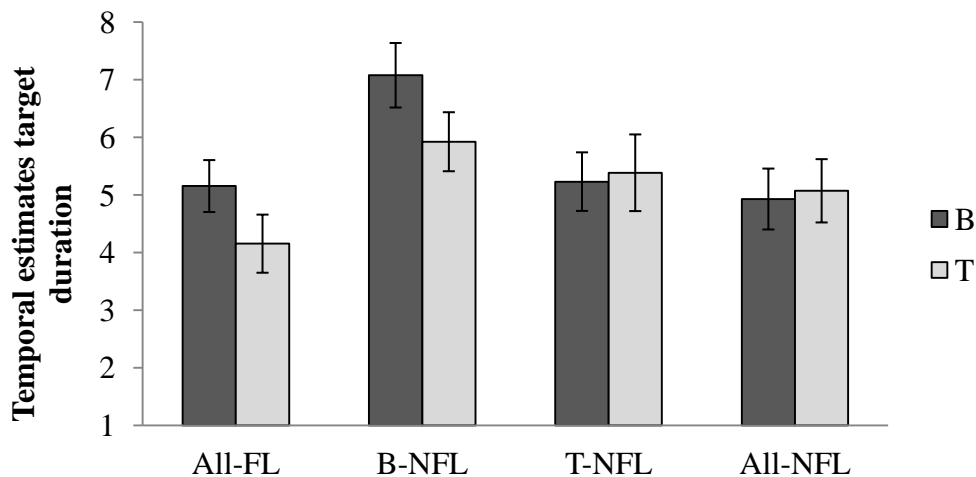
Figure 3.10. Temporal estimates for the target duration for the blocking (B) and target (T) cue per group. Error bars show ±1 *SEM*.

The main effect of Group and the previously mentioned interaction were probably due to the difference in estimates between Group All-FL and Group B-NFL and the uniformity of estimates for Group T-NFL and All-NFL. When comparing estimates for the former groups with a within subjects ANOVA with a two Cue (B and T) x two Group (All-FL and B-NFL), there was a main effect of Cue ($F(1, 24) = 7.89$, $p = 0.01$) and there was a main effect of Group ($F(1, 24) = 9.22$, p <0.01). There was no Cue x Group interaction ($F < 1$). When comparing Group T-NFL and All-NFL there was no main effect of Cue ($F < 1$), no main effect of Group ($F <1$) and no Cue x Group interaction ($F < 1$).

3.3.3 *Discussion*

This experiment showed attenuated blocking when most cues did not have a set location (Group All-NFL). Yet, blocking was found when only one cue, blocking or target, did not have a fixed location, or when all cues had a set location (Groups All-FL, B-NFL and T-NFL). Thus, participants did learn about the cue, not just the location. Therefore, the explanation for attenuated blocking that Dibbets et al. (2000) gave, that the participants only learned the position of the cues, cannot explain the results shown

here. Consequently, a different explanation for the lack of blocking when most of the cues do not have a set location (Group All-NFL) must be found. It seems that if participants only have the colour of the cue to remember and they cannot use location as a cue property for all the cues in the trial, they do not have enough information to learn which cue predicts lightning and which does not. In other words, one possible explanation for the lack of blocking is that there are not enough cue properties for participants to remember which cue is which. To investigate this further, Experiment 3.3 tested blocking and overshadowing when different cue properties were present and also looked at cue competition strength when the number of cue properties differed between groups.

The temporal estimates between the two overshadowing cues and the blocking cue did not differ when comparing groups, though the standard deviations did differ for the overshadowing cues. However, for the target cue there were differences between estimates when comparing groups. Temporal estimates for the target duration differed between blocking and target cue for groups in which the target cue had a set location, but not for groups in which the target cue was moving. The blocking cue and target cue estimates differed in groups in which the blocking cue did not have a set location. Therefore, the location of the blocking cue influenced the temporal estimates.

3.4   Experiment 3.3

In the previous experiment blocking was attenuated when participants could only recognise a cue by paying attention to its colour, so there was only one cue property to remember. Thus, blocking occurred when participants had two cue properties to remember. It may be easier for participants to be able to distinguish stimuli (or in this case lightning machine buttons) from each other if there are more characteristics to remember them by. Therefore, in this experiment it was tested whether the number of cue properties is important for blocking or whether it is a specific cue property that influenced blocking in previous experiments. Consequently, by changing the number of properties that participants could remember about a cue, the importance of the number of properties or elements participants could learn about cues was tested and whether this influenced blocking, or if it was specific cue properties that were important.

The experimenter differed for this experiment; the experiment was run by two Psychology students; Katie Rose and Stephen Harrison, who were in their third year. They recruited volunteers and ran the experiments for their final project.

3.4.1   Method

Participants

Sixty eight participants (59 females and 9 females) took part in this study. Ages ranged from 18 to 38, with a mean of 20.35 (*SD*: 3.35). Two participants were not native English speakers. All participants were Newcastle University students and were given research credit if they were Psychology students.

Stimuli

In Experiment 3.3 four sets of cues were used. The cue sets consisted of one set in which cues were all different colours and different shapes (see Figure 3.11a), cues that were uniform in shape but different colours (see Figure 3.11b), cues that were all the same colour but different shapes (see Figure 3.11c) and cues that were uniform in shape and colour (see Figure 3.11d). In groups in which colour was uniform stimuli were all blue, brown, green or purple.
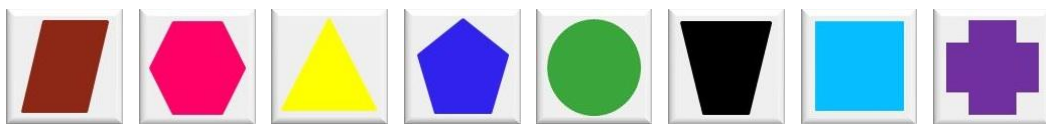
Figure 3.11a. Cue set for group with cues with different colours and different shapes.

Figure 3.11b. Cue set for group with cues with different colours and same shape.
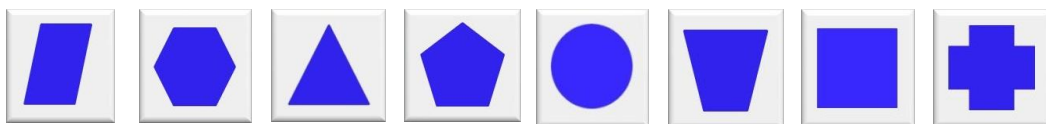
Figure 3.11c. Cue set for group with cues with same colour and different shapes.

Figure 3.11d. Cue set for group with cues with same colour and identical shape.

In this experiment a cue was added to the training and testing phase, namely the positive control, which enabled overshadowing to be analysed in the experiments. The positive control was presented six times (like the other cues or cue pairs) in the compound phase with one lightning bolt as a US, just like the two overshadowing control cues and the blocking and target cue pair. The positive control was also presented individually in the test phase to determine participants' causality ratings for this cue.

Procedure

In this experiment blocking and overshadowing were investigated in six groups, see Table 3.2. For Group DC-SS-FL and DC-SS-NFL the same cues were shown (see Figure 3.13b) as in both these groups cues were different colours and had an identical shape. Groups SC-DS-FL and SC-DS-NFL also shared the same set of cues (see Figure 3.13c) as in these groups cues were a different shape and uniform in colour. Participants were randomly assigned to a group. There were 13 participants in DC-SS-NFL and SC-DS-NFL, 12 participants in Group DC-DS-NFL and 10 participants in Group DC-SS-FL, SC-DS-FL, SC-SS-FL and DC-SS-NFL.

Table 3.2. Different experimental groups. Each group had a different combination of cue properties.

Group	Colour	Shape	Location	Nr. of elements
DC-DS-NFL	Different Colour	Different Shape	No Fixed Location	2
DC-SS-FL	Different Colour	Same Shape	Fixed Location	2
DC-SS-NFL	Different Colour	Same Shape	No Fixed Location	1
SC-DS-FL	Same colour	Different Shape	Fixed Location	2
SC-DS-NFL	Same colour	Different Shape	No Fixed Location	1
SC-SS-FL	Same colour	Same Shape	Fixed Location	1

The instructions for this experiment were similar to the previous experiment, but the instructions on what to pay attention to differed. In the first tutorial slide after the colour test participants were not told anything about which cue properties would be predictive of the outcome.

The durations in the temporal estimate test differed from Experiment 3.2. In this experiment, participants were shown cues for 1425, 1900 and 2375 ms. The duration test consisted of each cue, except for the pre-training cues, being shown for 1425, 1900 and 2375 ms and participants had to score on a Likert scale how the duration compared to the duration of the cue during training. The scale ranged from one to nine with one being shorter, five being the same (target duration) and nine being a longer duration.

Data analysis

Participants were excluded if they rated the causality for the negative control cue five or higher and the positive control cue as five or lower.

3.4.2 Results

Overshadowing

Ratings for the first and second overshadowing cue were very similar, the mean causality rating for the first overshadowing cue was 6.65 (*SD*: 3.04) and for the second cue was 5.96 (*SD*: 3.06). The causality ratings were submitted to a two Cue (O1 and O2) x six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) within-subjects analysis of variance (ANOVA) with both Cue and Group as repeated measures. The ANOVA showed no main effect of Cue ($F(1, 62) = 1.33$, $p = 0.25$). As the two overshadowing ratings did not differ, the mean was calculated to compare to the positive control to analyse overshadowing.

The causality ratings were submitted to a three Cue (O1, O2 and C) x six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) within-subjects ANOVA with both Cue and Group as repeated measures. There was a difference between ratings for the two overshadowing cues and the positive control as there was a main effect of Cue ($F(1, 62) = 243.21$, $p < 0.001$). There was no main effect of Group ($F(5, 62) = 2.33$, $p = 0.05$), and there was no Cue x Group interaction ($F(5, 62) = 2.28$, $p = 0.06$).

Causality ratings were also compared with ANOVAs, each comparing a different Factor with a three Cue (O1, O2 and C) x two Factor (comparing either Colour,

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Shape, Location or Number or Elements in groups) within-subjects ANOVA with both Cue and Factors as repeated measures. There was a main effect of Colour ($F(1, 66) = 9.53$, $p < 0.01$), see Figure 3.12. There was no main effect of Shape ($F < 1$), no main effect of Location ($F(1, 66) = 5.09$, $p = 0.03$) and no main effect of Number of Elements ($F < 1$).
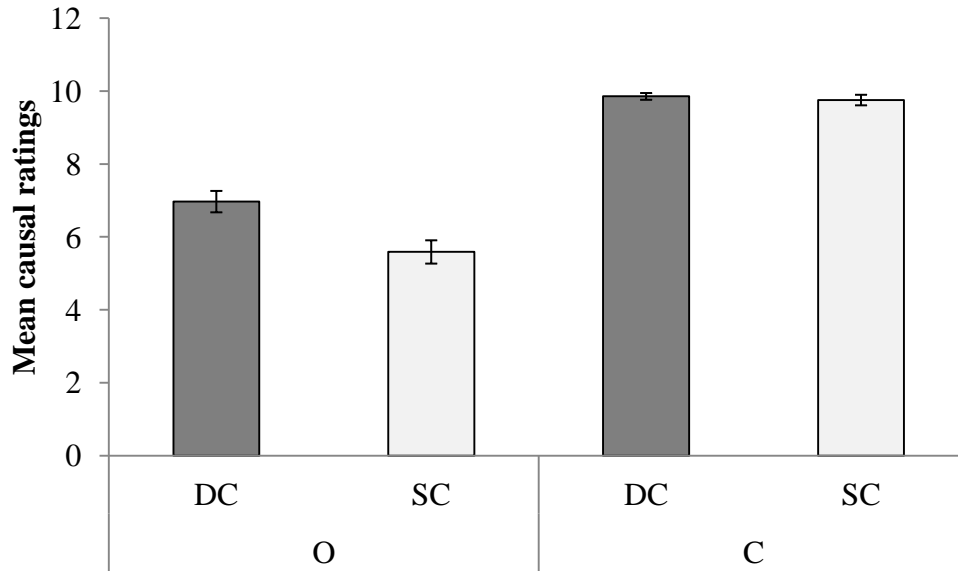
Figure 3.12. Mean causality ratings for overshadowing cue (O) and positive control (C) for groups in which all cues are the same colour (SC) and groups in which cues are all a different colour (DC). Error bars indicate ± 1 *SEM*.

Blocking

Blocking scores were calculated for all six groups, see Figure 3.13. In this experiment blocking was seen in the majority of the groups tested; DC-DS-NFL t (11) = 3.51, $p < 0.01$, DC-SS-FL t (9) = 3.19, $p = 0.01$, DC-SS-NFL t (12) = 4.69, $p < 0.01$ and SC- DS-FL t (9) = 2.74, $p = 0.02$, and SC-SS-FL t (9) = 2.80, $p = 0.02$ with the exception of Group SC-DS-NFL t (12) = 0.84, $p = 0.42$.
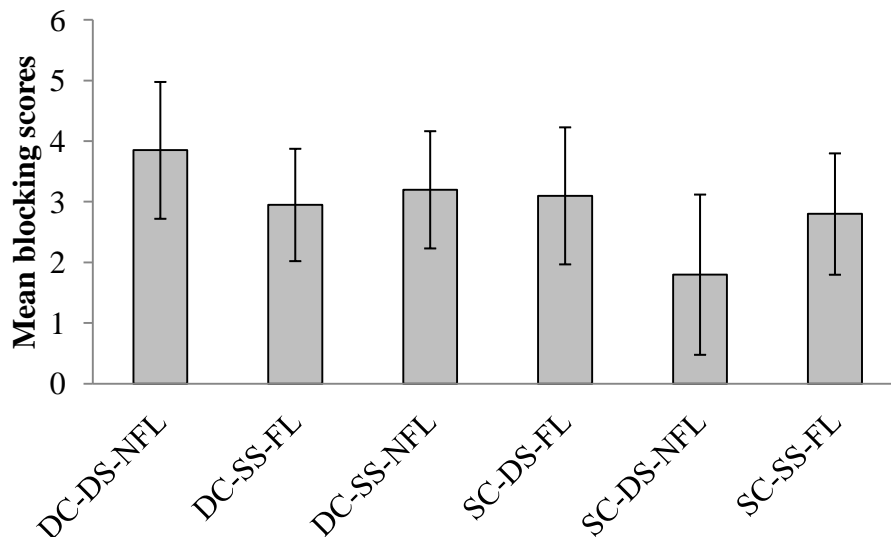
Figure 3.13. Mean blocking scores per group. Error bars show ±1 *SEM*.

To analyse blocking scores, a six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) between-subjects ANOVA with Group as a factor was conducted. There was no difference between blocking scores when comparing Groups; $F(5, 62) = 1.13$, $p = 0.36$.

An independent t-test analysis showed there was a main effect of Number of Elements ($t(66) = -0.94$, $p = 0.35$), the mean blocking score in groups with one element was 2.49 (*SD*: 3.58) and for two elements was 3.28 (*SD*: 3.33).

A one way ANCOVA with number of elements entered as covariate was conducted on various factors; analysis showed there was no main effect of Colour ($F(1, 64) = 1.90$, $p = 0.17$, $\eta_p^2 = 0.03$), no main effect of Shape ($F(1, 64) = 3.79$, $p = 0.06$, $\eta_p^2 = 0.06$) and no main effect of Location ($F < 1$, $\eta_p^2 < 0.01$). A one way ANCOVA with location entered as covariate was also conducted; analysis showed there was no main effect of Colour ($F < 1$, $\eta_p^2 = 0.01$) or Shape ($F < 1$, $\eta_p^2 = 0.01$). Thus, neither number of elements nor location influenced blocking.

Temporal estimation

Overshadowing & positive control cues

The means of the temporal estimates of the two overshadowing cues and the positive control were close to five, the first overshadowing cue had a mean of 5.67 (*SD*: 1.18), the second overshadowing cue mean was 5.41 (*SD*: 1.25) and the positive control mean was 5.57 (*SD*: 1.22). To compare temporal estimates for the three cues, temporal estimates were submitted to a three Cue (O1, O2 and C) x six Group (DC-DS-NFL, DC-

SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) within-subjects ANOVA with both Cue and Group as repeated measures. There was no difference between the three cues (no main effect of Cue: $F(2, 124) = 1.90$, $p = 0.15$). There was also no main effect of Group ($F(5, 62) = 1.27$, $p = 0.29$) and no Cue x Group interaction ($F(10, 124) = 1.12$, $p = 0.35$).

Standard deviations of the overshadowing cues and the positive control were compared in a similar manner; an ANOVA with a three Cue (O1, O2 and C) x six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) within-subjects ANOVA with both Cue and Group as repeated measures was conducted. The ANOVA results showed there was no difference between the three cues (no main effect of Cue: $F < 1$). No main effect of Group ($F(5, 62) = 1.65$, $p = 0.16$) was found and no interaction between Cue x Group was found ($F(10, 124) = 1.15$, $p = 0.33$).

Participants were not accurate at judging the target duration for the two overshadowing cues and the positive control as the target duration estimate for the first overshadowing cue was 5.51 (SD: 1.64), the second overshadowing cue estimate was 5.54 (SD: 1.69) and for the positive control the target duration estimate was 5.66 (SD: 1.86). A t-test showed target estimates differed from five for all three cues; first overshadowing cue $t(67) = 2.58$, $p = 0.01$, second overshadowing cue $t(67) = 2.66$, $p = 0.01$ and positive control $t(67) = 2.94$, $p < 0.01$.

The target duration (1900 ms) temporal estimates were submitted to a three Cue (O1, O2 and C) x six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) within-subjects ANOVA with both Cue and Group as repeated measures. There was no difference between target durations of the three cues, the ANOVA showed no main effect of Cue ($F < 1$). No main effect of Group ($F(5, 62) = 1.05$, p = 0.40) was found. There was no interaction between Cue x Group ($F < 1$).

A within- subjects ANOVA with a three Cue (O1, O2 and C) x two Factor (Groups with One Element and Groups with Two Elements) with Cue and Factor as repeated measures was also conducted. The Number of Elements did not influence target duration estimates (no main effect: $F(1, 66) = 3.86$, $p = 0.05$), though this was close to significance.

A one way ANCOVA with number of elements entered as covariate was conducted on various factors; there was no main effect of Colour ($F < 1$, $\eta_p^2 < 0.001$) or Shape ($F < 1$, $\eta_p^2 = 0.01$) for target duration estimates. There was also no main effect of Location ($F < 1$, $\eta_p^2 = 0.01$). A one way ANCOVA with location entered as covariate

was also conducted; analysis showed there was no main effect of Colour ($F < 1$, $\eta_p^2 = 0.01$) or Shape ($F < 1$, $\eta_p^2 < 0.01$). Thus, neither number of elements nor location influenced temporal estimates for the target duration for the two overshadowing cues and the positive control.

Blocking & target cue

Mean temporal estimates varied for the three test durations for the blocking cue, see Figure 3.17. To assess whether participants were accurate at assessing the three test durations for the blocking cue, the temporal estimates were submitted to a three Duration (1425, 1900 and 2375 ms) x six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) within-subjects ANOVA with both Duration and Group as repeated measures. There was a main effect of Duration ($F(2, 124) = 70.22$, $p < 0.001$). There was no main effect of Group ($F(5, 62) = 1.05$, $p = 0.40$) and there was no Duration x Group interaction ($F(10, 124) = 1.13$, $p = 0.35$).

The mean target cue temporal estimates varied for the three test durations; see Figure 3.14. A within-subjects ANOVA was also conducted to compare target cue temporal estimates of the three test durations with a three Duration (1425, 1900 and 2375 ms) x six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) ANOVA with both Duration and Group as repeated measures. There was a main effect of Duration ($F(2, 124) = 77.91$, $p < 0.001$), there was no main effect of Group ($F(5, 62) = 1.57$, $p = 0.18$) and no Duration x Group interaction ($F < 1$).
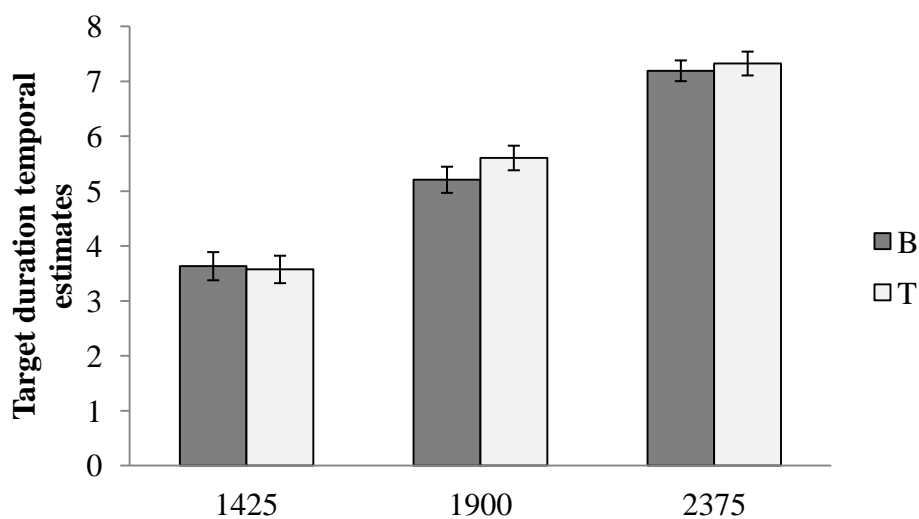
Figure 3.14. Mean temporal estimates for blocking (B) and target (T) cue per test duration (1425, 1900 and 2375 milliseconds). Error bars show ±1 *SEM*.

Standard deviations for the blocking and target cue mean temporal estimates were very similar, for the blocking cue the standard deviation was 2.19 and for the target cue was 2.26. The temporal estimates were submitted to a two Cue (B and T) x six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) within-subjects ANOVA with both Cue and Group as repeated measures. The ANOVA showed there was no difference between the standard deviations of the two cues; no main effect of Cue ($F < 1$), no main effect of Group ($F(5, 62) = 1.35$, $p = 0.26$) and no Cue x Group interaction ($F(5, 62) = 1.18$, $p = 0.33$).

Temporal estimates were also compared with a within-subjects ANOVA with a two Cue (B and T) x two Factor (comparing Groups with One Element and Groups with Two Elements) with both Cue and Factor as repeated measures. The ANOVA showed no main effect of Number of Elements ($F < 1$).

A one way ANCOVA with number of elements entered as covariate was also conducted; analysis showed there was no main effect of Colour on standard deviations ($F < 1$, $\eta_p^2 < 0.01$), no main effect of Shape ($F(1, 64) = 1.60$, $p = 0.21$, $\eta_p^2 = 0.02$) and no main effect of Location ($F < 1$, $\eta_p^2 = 0.01$). Also, a one way ANCOVA with location as covariate was also conducted; there was a main effect of Colour ($F(1, 64) = 5.10$, $p = 0.03$, $\eta_p^2 = 0.07$) and no main effect of Shape ($F < 1$, $\eta_p^2 = 0.01$). Therefore, it can be concluded that overall the different cue properties or number of cue properties did not influence standard deviations of mean temporal estimates.

A student t-test showed the blocking cue target duration estimates did not differ from a score of five (*M*: 5.21, *SD*: 1.97, $t(67) = 0.86$, $p = 0.39$) and the target cue estimates did differ from five (*M*: 5.60, *SD*: 1.85, $t(67) = 2.69$, $p < 0.01$).

The temporal estimates for the target duration (1900 ms) were submitted to a two Cue (B and T) x six Group (DC-DS-NFL, DC-SS-FL, DC-SS-NFL, SC-DS-FL, SC-DS-NFL and SC-SS-FL) within-subjects ANOVA with both Cue and Group as repeated measures. The ANOVA showed no main effect of Cue ($F(1, 62) = 1.21$, $p = 0.28$), therefore there was no difference in target duration estimates between the blocking cue and the target cue. There was also no main effect of Group ($F(5, 62) = 1.58$, $p = 0.18$) and there was no Cue x Group interaction ($F(5, 62) = 1.05$, $p = 0.40$).

A similar ANOVA comparing Number of Elements as a Factor instead of Groups as a repeated measure showed there was a main effect of Number of Elements ($F(1, 66) = 5.88$, $p = 0.02$), see Figure 3.15.

Two separate student t-tests showed that in groups with one element, target duration estimates were similar to five (blocking cue: $t(35) = -0.92$, $p = 0.36$, target cue:

$t(35) = 1.23$, $p = 0.23$), but in groups with two elements, estimates differed from five (blocking cue: $t(31) = 2.44$, $p = 0.02$, target cue: $t(31) = 2.50$, $p = 0.02$).

A one way ANCOVA with Number of Elements as covariate was conducted for every main effect; there was no main effect of Colour ($F < 1$, $\eta_p^2 < 0.01$), no main effect of Shape ($F < 1$, $\eta_p^2 = 0.01$) or Location ($F(1, 64) = 1.50$, $\eta_p^2 = 0.02$). A one way ANCOVA with location as covariate showed there was no main effect of Colour ($F(1, 64) = 2.09$, p $= 0.15$, $\eta_p^2 = 0.03$) and no main effect of Shape ($F < 1$, $\eta_p^2 < 0.01$). These results indicate that cue properties and number of cue properties did not influence estimates.
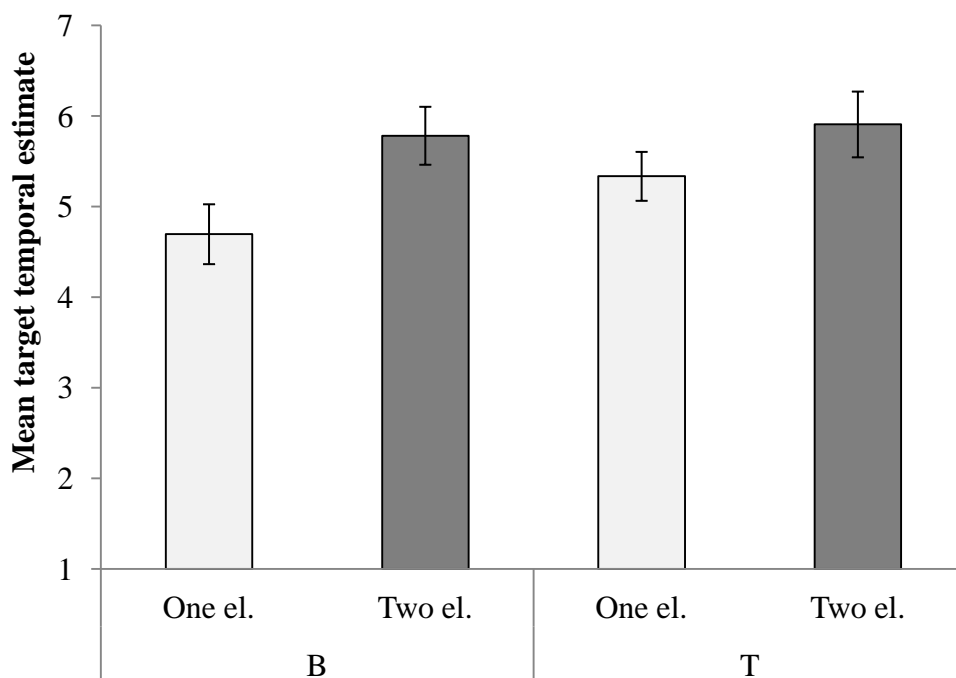
Figure 3.15. Mean temporal estimates for target duration for blocking (B) and target (T) cue for groups in which participants relied on one element (One El.) to distinguish cues by or two elements (Two El.). Error bars show ±1 *SEM*.

3.4.3   Discussion

Overshadowing was seen in all groups and colour of cues affected causality ratings of the overshadowing cues and the positive control. Blocking was found in most groups, except in the group in which cues were the same colour, had a different shape and did not have a fixed location (SC-DS-NFL). The different factors did not influence

blocking scores. Thus, the cue properties and the number of elements did not affect causality ratings very much.

Mean temporal estimates of the overshadowing cues and positive control cue were not accurate. However, the target duration estimates for the overshadowing cues and control cue were accurate. Temporal estimates for the blocking and target cue were accurate, and for target duration there was an effect of number of elements. In other words, the number of cue properties participants had to distinguish cues by influenced temporal estimates.

3.5   General discussion

In the first two Experiments (3.1 and 3.2), blocking occurred in groups in which cues had fixed locations and blocking was attenuated in groups in which cues had variable locations during training and testing. However, this was not the case for Experiment 3.3 in which only one group showed attenuated blocking, namely the group in which stimuli were the same colour, had a different shape and did not have a fixed location (SC-DS-NFL). It was predicted that blocking and overshadowing would be attenuated when cues did not have a set location (Dibbets et al., 2000), and this is what was observed in Experiments 3.1 and 3.2. However, Experiment 3.3 did not show an effect of location on blocking, and did not support the prediction.

In Experiment 3.3 there was an effect of number of elements on blocking. The blocking score for groups in which participants had one element to distinguish cues by was lower than when participants had two elements. Thus, blocking was slightly higher when participants were shown cues that were more similar (shared more elements). These results are in contrast to the Generalization Theory formulated by Pearce (1987), which predicts that when cues share more elements, more generalization between cues occurs. Thus, groups which share two elements would show less blocking than groups which share one element, as groups which share more elements should show more generalization. Yet, the opposite was found; when more elements were shared between cues, blocking was greater. However, the results can be explained by a different phenomenon, namely cue interference effects (Amundson & Miller, 2008). This is when information acquired previously interferes with the retrieval of associations later in training. Amundson and Miller (2008) suggest that cue interference increases with cue similarity. In the experiments above, groups in which two elements were present showed greater similarity, thus could have shown increased interference compared to

groups with one element. Increased interference would lead to greater blocking (Amundson & Miller, 2008).

Dibbets et al. (2000) also showed attenuated blocking in a stock market paradigm experiment; when cues did not have a set location blocking would be weaker than in the groups in which cues had set locations, they argued that participants learned the position of the cues, not the cues themselves. The instructions Dibbets et al. (2000) provided to participants did not specify whether cues had a fixed location or not, they simply stated participants needed to pay attention to cues. However, in Experiment 3.3 where no instructions were given about cue properties, blocking was observed in conditions in which cues did not have a fixed location. In Experiment 3.1 and 3.2, where cue location did affect blocking, participants were told cues could have a random location. Thus, it seems in the experiments in this chapter that instructions might have influenced causality ratings.

It was predicted that the cues that did not have a set location would be perceived as moving and so would be judged as having a longer duration (Fraisse, 1984), or that cues without a fixed location would have an added level of complexity and would be overestimated (Mate et al., 2009). Participants probably did not perceive the cues as moving when they did not have a set location, because the temporal estimates for an individual cue did not vary in groups in which cues had a set location and a varied location, or for individual stimuli that did not have a fixed location (Experiment 3.2). There was no main effect of location on temporal estimates in any of the experiments; therefore participants probably did not view a cue as more complex because of the cue location.

In Experiment 3.1 and 3.3 a main effect of Colour was observed for standard deviations for blocking and target cue. Thus, the findings here do provide support for the theory that removing some of the colour information in cues changes overt attention participants pay to them (Frey et al., 2011). Previous studies have shown that cue colour has also been shown to influence cue competition (Graham et al., 2006), though this was not the case in Experiment 3.1 and 3.3 as blocking was shown in both.

In Experiment 3.3 there was an effect of number of elements on temporal estimates for target duration of the blocking and target cue. When participants could distinguish cues by one element, they were accurate at estimating the target duration, whilst when they had two elements, they were inaccurate. An extra stimulus element could add a level of complexity (Bricker, 1955). Previous studies have found that temporal estimate accuracy decreases when complexity of the amount of non-temporal

information increases in conditioning trials (Aubry et al., 2008; Poynter & Homa, 1983; Zakay, 1998). Poynter and Homa (1983) found that more complex stimuli caused participants to overestimate durations. When Poynter and Homa (1983) presented participants with regular patterns of flashing lights (less complex), participants were more accurate at temporal estimates than when irregular patterns were presented (more complex).

It was predicted that temporal estimates and variance in the data would be similar for all cues as modality did not vary, which is in accordance with the SET model (Gibbon, 1991) as all cue properties were visual. However, the temporal results of Experiment 3.1 and 3.2 could not be explained by the SET (Gibbon, 1991) as there was a variation in temporal estimates between groups and differences in variance. Findings in Experiment 3.3 did support the SET model (Gibbon, 1991) as it does not make any predictions about number of cue properties, only modalities and standard deviations of temporal estimates. There was no difference between cues or groups in the majority of temporal estimates, therefore, the results were largely in line with the SET.

In Experiment 3.2 blocking was seen in the group in which all cues had a set location, but also in the groups in which only one cue did not have a set location. When only the blocking or target cue did not have a fixed location, this did not affect blocking; it was only in the group in which multiple cues did not have a fixed location that attenuation of blocking occurred. Thus, blocking was not only influenced by the blocking and target cue, but by all the cues in the trial which is in line with different associative learning models such as the Rescorla Wagner theory (1972) since according to the RW model change in associative strength for one cue (V_A) is calculated using the associative strength of all other cues in one trial (V_T).

It can be concluded from these experiments that location is an important cue property which aides participants in causality rating (Dibbets et al., 2000) and that cue colour and number of elements influenced temporal estimates. The results do not show attenuation of blocking and inaccurate timing in the same groups- which would be expected if associations and durations are encoded together, thus experiments in this chapter do not support that theory (e.g. Balsam & Gallistel, 2009; Honig, 1981; Savastano & Miller, 1998).

Chapter 4. Cue duration effects during causal learning: overshadowing and blocking

4.1   Introduction

Stimulus duration is important in conditioning and associative learning (Barnet, Grahame, & Miller, 1993; Savastano & Miller, 1998). Pavlov (1927) showed that delay conditioning in which subjects were trained with a CS at a certain time point, and then delaying the CS would cause responding to the CS to stop. Therefore, the timing of the CS influenced responding. This has led researchers to hypothesise how timing in animals and humans works (Church et al., 1994; Gibbon & Balsam, 1981). For example, Church et al. (1994) proposed timing was controlled and remembered by means of an internal clock, whilst others have suggested that conditioning depends on whether subjects learn the durations of intervals between CSs and USs (Gallistel & Gibbon, 2000; Gibbon & Balsam, 1981).

Studies have also shown CR is influenced by ITI and CS duration; when the CS increases relative to the ITI a decrease in CR is observed (Barnet, Grahame, & Miller, 1995; Holland, 2000; Lattal, 1999). Subsequently, certain timing models have included CS and ITI durations (e.g. Scalar Timing Theory, SET: Gibbon & Balsam, 1981). According to SET, individuals are sensitive to the ratio between the CS and ITI durations (I/T ratio). At the basis of the ratio lies the idea that during conditioning the rate of reinforcement during the CS is greater than during the ITI, and as the ratio between these two features decreases, the animal learns about the relationship between the CS and outcome with increasing rapidity. Thus, under this timing model, acquisition of the CR is expected to proceed at a higher rate as the I/T ratio declines (see also Gallistel & Gibbon, 2000, 2002).

However, while SET predicts associations according to ratio of CS and ITI duration during training, these associations can also be predicted by associative learning models. The Mackintosh (1975b) and Pearce and Hall (1980) model for example, do not make any predictions about the influence of stimulus duration or ITI on associative strength. However, under a general learning framework such as the RW model (Rescorla & Wagner, 1972) the training context acquires associative strength as a result of repeated pairings of the CS and the US. If the ITI is short the model predicts that the context will undergo little extinction and will, to a certain extent, overshadow the CS when it is presented. If the ITI is long then the context is predicted to undergo higher

levels of extinction (and lower levels of cue competition with the CS) and thus the CS will acquire associative strength at a greater rate (Mustaca, Gabelli, Papini, & Balsam, 1991).

The SOP (Wagner, 1981) also predicts that associative strength depends on CS and ITI duration; the SOP model hypothesises that there are three states in which CS can be in; A1 (active state at the centre of attention), A2 (active state at the periphery of attention, no learning possible) and I (inactive state). These define the strength of the association between CS and US. Consequently, trial spacing is important as the CS can be encountered in the 'wrong' state (Wagner, 1981). For example, if the ITI is longer, then the CS will have decayed into the I state and is available for conditioning. However, if the ITI is shorter, CS will be in A2, and learning will not be possible.

Studies have also been conducted looking at trial spacing effects, CS duration and ITI duration on cue competition (e.g. Fairhurst, Gallistel, & Gibbon, 2003; Kamin, 1969; Kehoe, 1983; Kehoe et al., 1981; Sissons, Urcelay, & Miller, 2009; Wheeler & Miller, 2007). Kehoe (1983) tested overshadowing in the acquisition of the nictating membrane response in rabbits. He found that overshadowing was attenuated when CS2 was shorter (400 or 600 ms) than CS1 (800 ms), compared to when both were 800 ms. This is in line with what Egger and Miller (1962) hypothesised, namely that rats would ignore the shorter duration as this was redundant.

Some studies have also found no effect of stimulus duration on overshadowing (Jennings et al., 2007; McMillan & Roberts, 2010). Jennings et al. (2007) tested whether overshadowing would be influenced if the duration of an overshadowing stimulus (CS1) was longer or shorter than its target (CS2) when presented in compound. They tested four groups; Group 'Short' (S) in which the duration of CS1 was shorter than CS2, Group 'Longer' (L) in which the duration was much longer, Group 'Matched' (M) in which CS1 and CS2 were both the same length and a control group in which only CS1 was presented. Jennings et al. (2007) found that responding was highest in the Group M. They also found that overshadowing occurred in all three groups, and it was equally strong in the three groups. Jennings et al. (2007) suggested that the discrepancy between the results of their study and Kehoe (1983) could lie in the difference of the stimulus durations in experiments. In Jennings et al. (2007) CS durations varied between 10 and 40 s, whilst in Kehoe the durations ranged from 400 to 800 ms.

Previous studies have also looked at CS durations in a different cue competition phenomenon, namely blocking (Gaioni, 1982; Jennings & Kirkpatrick, 2006; Kehoe et al., 1981). Kehoe et al. (1981) tested blocking of the nictating membrane response and

found that a long CS1 (800 ms) could block a short CS2 (400 ms) where the ITI was 400 ms between CS1 and US, and 800 ms between CS2 and US. Gaioni (1982) conducted experiments in rats testing whether blocking was influenced by having a variable CS (in Phase 1 CS1was 3 min, in Phase 2 CS1 varied between 30 s to 3 min with mean of 3 min and CS2 was 30 s) instead of a constant CS duration. In the first training phase Gaioni (1982) still found blocking in the conditions in which the duration was variable and he found no difference when comparing responding to the variable duration stimulus to the stimulus in a condition in which the stimulus duration was constant. Therefore, duration and contiguity of CS and US did not influence blocking in these experimental setups.

Gaioni (1982) found that a longer cue could block a shorter cue, however, Jennings and Kirkpatrick (2006) showed that shorter stimuli often cannot block longer target stimuli (Jennings & Kirkpatrick, 2006). Jennings and Kirkpatrick (2006) set up two experiments to study duration influences in blocking; one in which stimulus durations were 10s and 90s, and a second in which durations were 10s and 15s. Jennings and Kirkpatrick (2006) found less responding when a long cue was shown first, but not when the durations were reversed (short in the first phase); i.e. a long CS1 blocked a short CS2, but not vice versa. Thus, studies found that a long CS duration is more effective at blocking than a short CS durations (compared to duration of target cue) (Jennings & Kirkpatrick, 2006), but that other changes in temporal contiguity (Kehoe et al., 1981) or difference in duration of blocking and target stimulus do not influence blocking (Gaioni, 1982).

Results from animal literature indicate that stimulus duration can influence associative strength, this could be because stimuli and their durations might be encoded together (e.g. Balsam & Gallistel, 2009; Honig, 1981; Savastano & Miller, 1998). The current chapter will look at effects of stimulus duration on both overshadowing and blocking. As noted above, previous studies have shown varied stimulus duration effects during overshadowing. There is evidence to support the prediction that there will be no effect (Jennings et al., 2007; McMillan & Roberts, 2010), or an attenuation of overshadowing if the target is either shorter *or* longer in (Kehoe, 1983). Therefore, no definite prediction can be made. Previous research about blocking has shown that longer durations block shorter durations (Jennings & Kirkpatrick, 2006), thus, it was predicted that a blocking cue with a longer duration than the target cue would show blocking, and that a blocking cue with a shorter duration than target cue would attenuate blocking.

4.2   Experiment 4.1

The purpose of this experiment was to investigate overshadowing and blocking with a similar setup to previous non-human animal studies (Jennings et al., 2007). Participants were assigned to one of three experimental groups (Matched, Longer or Shorter) in which the duration of the blocking stimulus was matched, longer or shorter (dependent on experimental group) than the target stimulus in order to determine the effects of stimulus duration on the magnitude of both overshadowing and blocking (Jennings et al., 2007; Jennings & Kirkpatrick, 2006). The setup of Experiment 4.1 was identical to Experiment 3.2, however one extra cue was added; an extra positive control in the compound phase. Therefore, two control cues were presented individually in the compound phase in order to facilitate an investigation of overshadowing.

4.2.1   Methods

Participants

Thirty eight participants took part in Experiment 4.1 (18 female, 20 male). Ages ranged from 18 to 53 year old (*M:* 23.45, *SD*: 7.13). Eleven participants were not native English speakers. There were 13 participants in Group Longer (L) and Group Shorter (S) and 12 in Group Matched (M). Participants were Newcastle University undergraduates or members of the public who had volunteered by registering for the Institute of Neuroscience volunteer scheme. Participants were paid £4 for taking part.

Stimuli

The setup and stimuli were identical to Experiment 3.2 with the exception of the addition of an extra positive control stimulus. Therefore, instead of eight stimuli, there were nine. The cues used in the present experiment were a uniform square shape (3 wide x 3.4 cm high) with a black border; the cues did however differ in that in-filled colour of each cue was unique.

Procedure

In Group Matched (M) all cue durations were matched (all 1900 ms) and this group, therefore, followed a typical design for cue competition type studies, see Table 4.1 The groups of interest in the present experiment were Group Longer (L) and Group Shorter (S); in these groups the duration of the overshadowing cues (O1 and O2) and control cues (C1 and C2) were either 25% longer (Group L: second pre-training cue,

target cue, second overshadowing cue and second positive control) or 25% shorter (Group S: second pre-training cue, target cue, first overshadowing cue and second positive control) in duration than the target cue.

Table 4.1 Duration of stimuli per group. Letters in the top row represent; pre-training stimuli (P1 and P2), blocking stimulus (B), target stimulus (T), overshadowing controls (O1 and O2), negative control (N), and positive controls (C1 and C2).

	Group L	Group S	Group M
P1	1900	1900	1900
P2	2375	1425	1900
B	2375	1425	1900
T	1900	1900	1900
O1	1900	1425	1900
O2	2375	1900	1900
N	1900	1900	1900
C1	1900	1900	1900
C2	2375	1425	1900

All conditions were counterbalanced and intertrial intervals were identical to Experiment 3.2; lightning buttons would be off for 500 ms before and after CS presentation, the US was shown for 2500 ms and the ITI was 1500 ms. The experiment was programmed for stimulus offset to be simultaneous, therefore in Group S where the blocking cue was shorter than the target cue, the target cue would appear first in the compound training phase and be on for 475 ms, at which point in time the blocking cue would appear. Then both cues would be on for 1425 ms, and then both would switch off. For Group L the blocking cue would switch on first, for 475 ms, and then the target cue would switch on and both cues would be shown for another 1900 ms. Both cues would switch off at the same time.

Instructions and procedure for causality ratings (training and testing) for this experiment were identical to Experiments 3.1 and 3.2. All stimuli were shown for: 950, 1425, 1900, 2375 and 2875 ms. Therefore, every stimulus was shown five times in the timing test.

Overshadowing and blocking were calculated in the same way as Experiment 3.3 but, to determine whether overshadowing had taken place, cues with matched durations were compared. For Group M the mean causality rating for both overshadowing cues and the mean causality rating for both positive controls was calculated and used for all analyses. To assess the temporal estimates of target durations, estimates of cues of their target durations were compared; i.e. temporal estimates of cues which were shown for 1900 ms were compared to cues with a target duration of 1425 ms and 2375 ms.

4.2.2   Results

Overshadowing

Mean causality ratings for overshadowing cues varied between the two cues for Group S, but also across groups; ratings for Group M were higher than Group L, see Figure 4.1. The causality ratings were submitted to a two Cue (O1 and O2) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. When comparing mean causality ratings there was no main effect of Cue ($F(1, 35) = 3.63$, $p = 0.07$), however there was a main effect of Group ($F(2, 35) = 3.59$, $p = 0.04$ and a Cue x Group interaction ($F(2, 35) = 3.68$, $p = 0.04$). The interaction and main effect of Group were probably due to the difference in ratings for Group S.

When only comparing ratings for Group L and M with a within-subjects ANOVA with a two cue (O1 and O2) x two Group (L and M) with Cue and Group as repeated measures there was no main effect of Cue ($F < 1$), no main effect of Group ($F < 1$) and no Cue x Group interaction ($F < 1$).

The causality ratings of the overshadowing control cues in Group L were submitted to a two Cue (O1 and O2) between-subjects ANOVA. This showed a main effect of Cue ($F(1, 12) = 8.37$, $p = 0.01$) for Group S.

The causality ratings of the control cues were submitted to a two Cue (C1 and C2) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. This was not the case for the positive control cues; the mean causality rating for the first positive control was 9.61 (SD: 1.79) and for the second positive control was 9.71 (SD: 1.14). There was no main effect of Cue ($F < 1$), no main effect of Group ($F < 1$) and also no Cue x Group interaction ($F(2, 35) = 2.19$, $p = 0.13$) for the positive control cues.
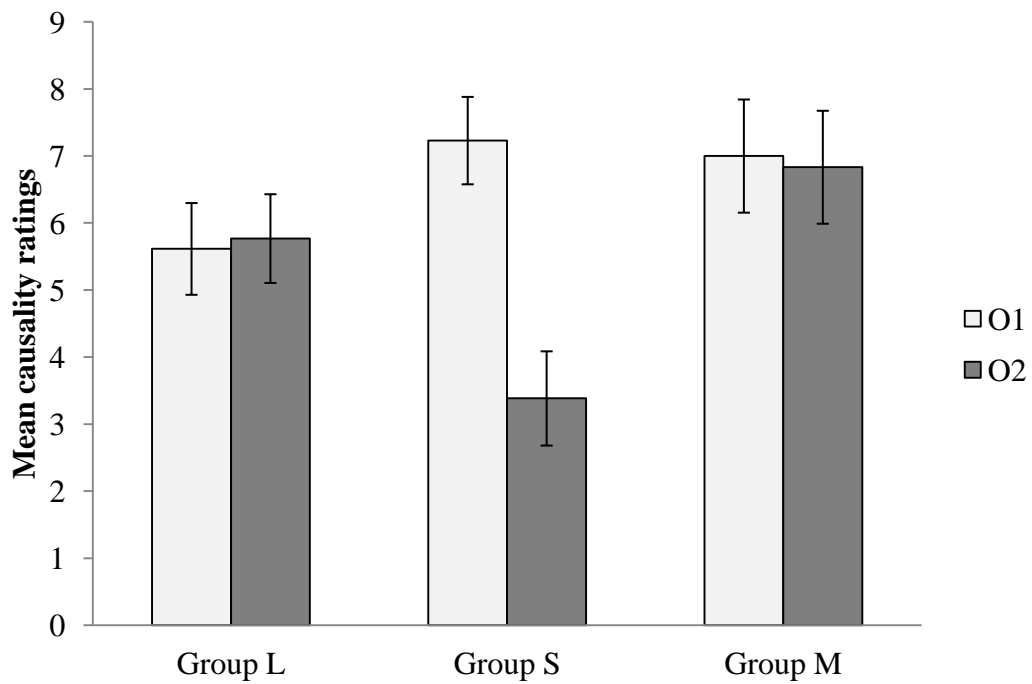
Figure 4.1. Mean causality ratings for both overshadowing cues (O1 and O2) for Group L, S and M. Error bars show ± 1 *SEM*.

Means of the overshadowing and positive control cue that were both 2375 ms in Group L varied greatly; the overshadowing cue mean was 5.77 (*SD*: 2.39) and the positive control the mean was 10 (*SD*: 0). To compare causality ratings the cues were submitted to a two Cue (O2 and C2) between-subjects ANOVA. There was a main effect of Cue ($F(1, 12) = 40.88$, $p < 0.001$).

Group S showed similar results when comparing the overshadowing and positive control cue causality ratings with durations of 1425 ms. The overshadowing cue mean was 3.38 (*SD*: 2.53) and the positive control cue mean was 9.15 (*SD*: 1.86). A between- subjects ANOVA with a two Cue (O1 and C1) factor showed there was a main effect of Cue ($F(1, 12) = 48.84$, $p < 0.001$).

The overshadowing cues and positive control cues which were all shown for 1900 ms were also compared, see Figure 4.2. The causality ratings were submitted to a two Cue (O1 and C1) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. There was a main effect of Cue ($F(1, 35) = 37.06$, $p < 0.001$), no main effect of Group ($F < 1$) and no Cue x Group interaction ($F(2, 35) = 2.66$, $p = 0.08$). Thus, overshadowing was found in all groups and it can be concluded that the duration of the blocking cue relative to the target cue (or different durations of overshadowing cues) did not affect overshadowing.
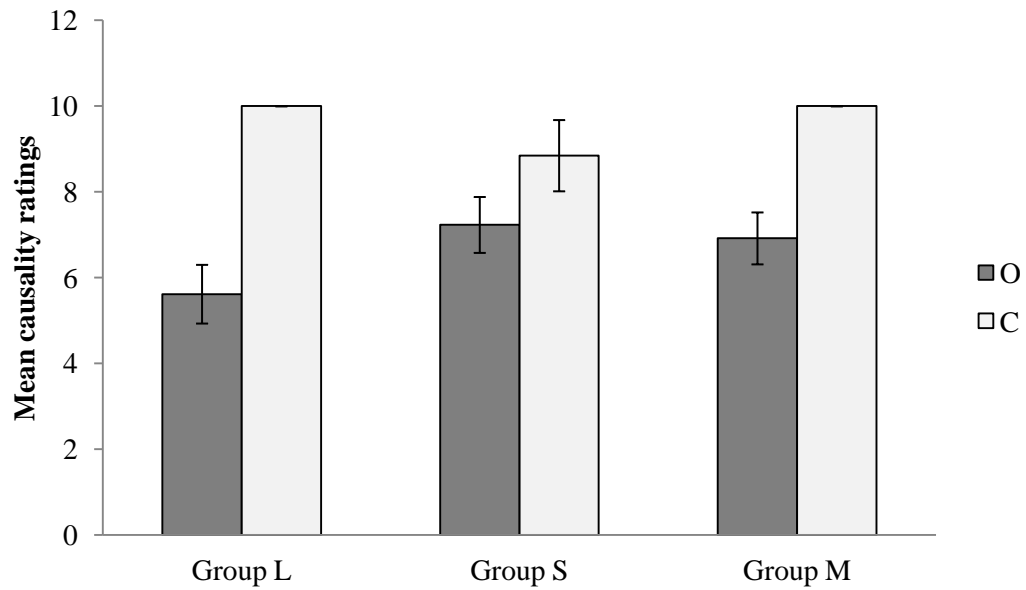
Figure 4.2. Mean causality ratings for overshadowing cue (O) and positive control cue (C) with 1900 ms duration for Group L, S and M. Error bars show ± 1 *SEM*.

Blocking

The mean blocking scores were very similar across the three groups, see Figure 4.3. Blocking was observed in all groups; Group L: $t(12) = 4.86$, $p < 0.001$, Group S: $t(12) = 2.50$, $p = 0.03$ and Group M: $t(11) = 2.54$, $p = 0.03$.

The blocking scores were compared with a between-subjects ANOVA with Groups (L, S and M) as a Factor. No main effect of Group was found ($F < 1$) when testing the difference between groups.
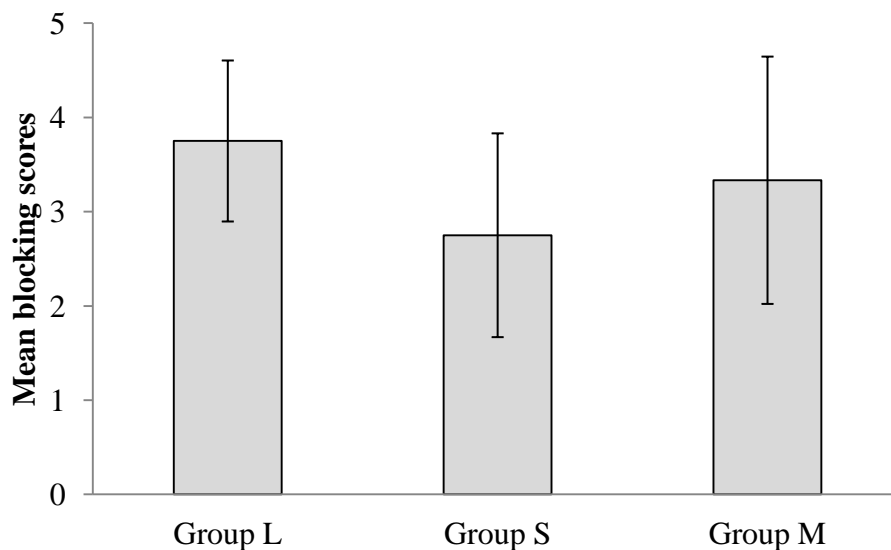
Figure 4.3. Mean blocking scores for Group L, S and M. Error bars show ± 1 *SEM*.

Mean temporal estimates for the overshadowing cues and positive control cues were approximately nine, see Figure 4.4. An ANOVA investigated whether the mean durations for the overshadowing and positive control cues were similar. The temporal estimates of the control cues were submitted to a four Cue (O1, O2, C1 and C2) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. This showed that cues had similar mean estimates; no main effect of Cue ($F(3, 105) = 1.97$, $p = 0.12$). It also showed that there was no difference between groups; no main effect of Group ($F < 1$) and no Cue x Group interaction ($F(6, 105) = 1.22$, $p = 0.30$).
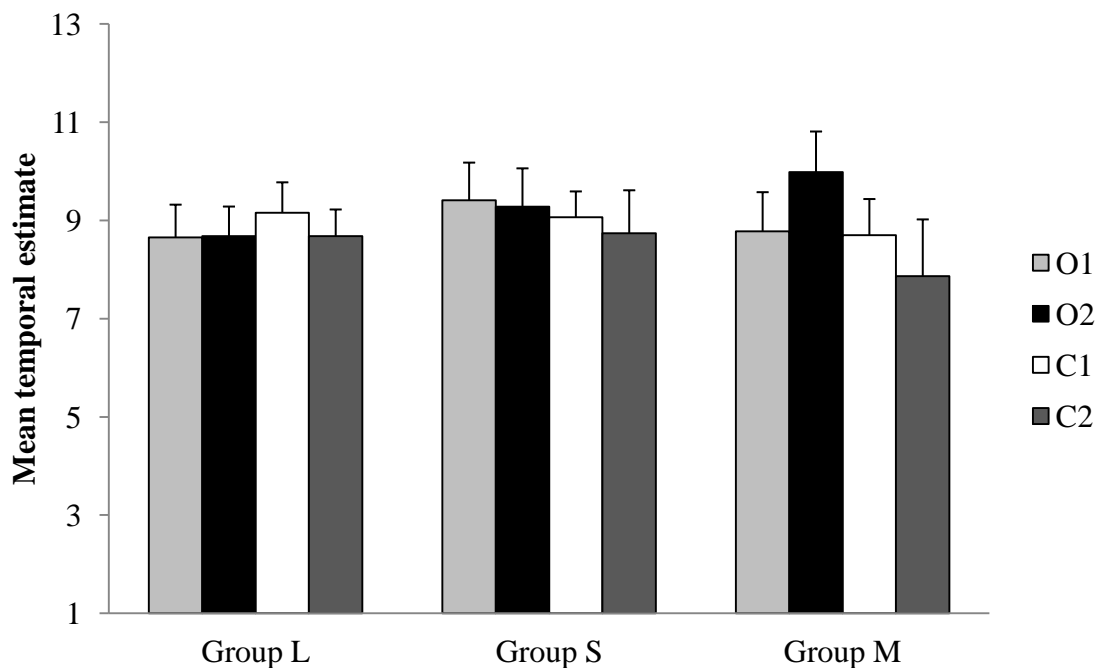
Figure 4.4. Mean temporal estimates for the two overshadowing controls (O1 and O2) and for the two positive controls (C1 and C2) for Group L, S and M. Error bars show + 1 *SEM*.

Temporal estimates for the four cues were very homogenous as the coefficients of variance were very similar; the coefficient of variance for the first overshadowing cue was 0.55, for the second cue was 0.51, for the first positive control was 0.54 and for the second positive control was 0.46. To analyse whether there was a difference in variance in estimates between cues, an ANOVA was also conducted comparing the coefficients of variance of the two overshadowing cues and the positive control cues.

The coefficients of variance of temporal estimates of control cues were submitted to a four Cue (O1, O2, C1 and C2) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. No main effect of Cue was found ($F(3, 105) = 2.26$, p = 0.09), no main effect of Group was found ($F(2, 35) = 1.78$, $p = 0.15$) and no Cue x Group interaction was present ($F < 1$).

Overshadowing and positive controls that were shown for 1900 ms throughout training and testing were also compared. The mean temporal estimate for the overshadowing cues that were presented for 1900 ms during training was 8.91 (*SD*: 3.75) and the mean temporal estimate for positive controls was 9.81 (*SD*: 3.45). The temporal estimates were submitted to a two Cue (O1 and C1) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. There was no main effect of Cue ($F(1, 34) = 2.67$, $p = 0.11$), no main effect of Group ($F(2, 34) = 1.20$, $p = 0.31$) and no Cue x Group interaction ($F < 1$). Therefore, there was no difference between cues and groups, indicating that the duration of the blocking cue did not influence duration estimates of the overshadowing and positive control cues.

Blocking & target cue

The temporal estimates per test duration were compared to see if people were able to distinguish the different test durations. There was a main effect of Duration ($F(4, 140) = 96.90$, $p < 0.001$), see Figure 4.5, showing there was a difference between test durations for the blocking cue. The temporal estimates of the blocking cue were submitted to a five Duration (950, 1425, 1900, 2375 and 2850 ms) x three Group (L, S and M) within-subjects ANOVA with both Duration and Group as repeated measures. There was no difference between temporal estimates when comparing groups (no main effect of Group: $F < 1$), and there was no Duration x Group interaction ($F(8, 140) = 1.67$, $p = 0.11$). The analysis for the target cue showed comparable results. When comparing temporal estimates for the test durations, there was a main effect of Duration ($F(4, 136) = 60.74$, $p < 0.001$), see Figure 4.5. There was no main effect of Group ($F < 1$) and no Duration x Group interaction ($F < 1$).

Figure 4.5. Mean temporal estimates for the blocking cue (B) and for the target cue (T) per test duration (in ms). Error bars show ± 1 *SEM*.

The coefficient of variance for the blocking cue and target cue was 0.55 for both cues when looking at variance for all test durations. To analyse whether there was a difference in the variance for the temporal estimates between the blocking and the target cue, the coefficient of variance for the blocking cue and target cue were submitted to a two Cue (B and T) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. The GLM showed no main effect of Cue ($F < 1$), no main effect of Group ($F(2, 35) = 1.54$, $p = 0.23$) and there was also no Cue x Group interaction ($F < 1$).

The temporal estimates of the target durations of the blocking and target cue were also analysed. The temporal estimates of 2375 ms duration for the blocking cue in Group L, the estimates of the 1425 ms duration for the blocking cue in Group S, the 1900 ms estimates of the target cues in the three groups and the 1900 ms temporal estimates of the blocking cue in Group M were compared to nine in a t-test (see Table 4.2). The t-tests showed that only the target duration of the blocking cue in Group L was not correctly estimated. All other mean estimates were correct.

Table 4.2. T-tests comparing target duration estimates of blocking (B) cue and target (T) cue in Group L, S and M.

Group	Cue	t	df	p
L	B	3.03	12	0.01
L	T	-0.31	12	0.76
S	B	-1.26	12	0.23
S	T	-0.16	12	0.88
M	B	0.73	11	0.48
M	T	0.17	11	0.87

The temporal estimates for blocking and target cue were submitted to a two Cue (B and T) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. This showed no main effect of Cue ($F < 1$), therefore there was no difference in temporal estimates for blocking and target cue, see Figure 4.6. There was also no main effect of Group ($F < 1$) and no Cue x Group interaction ($F(2, 35) = 2.37$, $p = 0.11$). To conclude, the durations of the blocking cue did not affect temporal estimates of the target cue. Participants did find it harder to give correct estimates for the blocking cue when the duration was longer that the target cue duration, but this was not the case when the blocking cue duration was shorter.
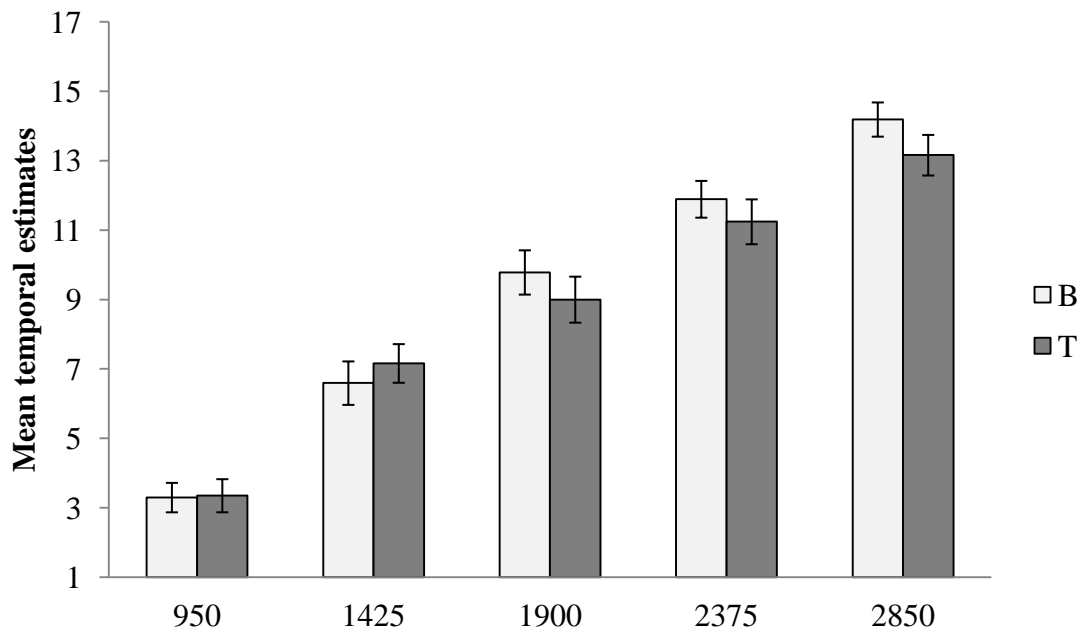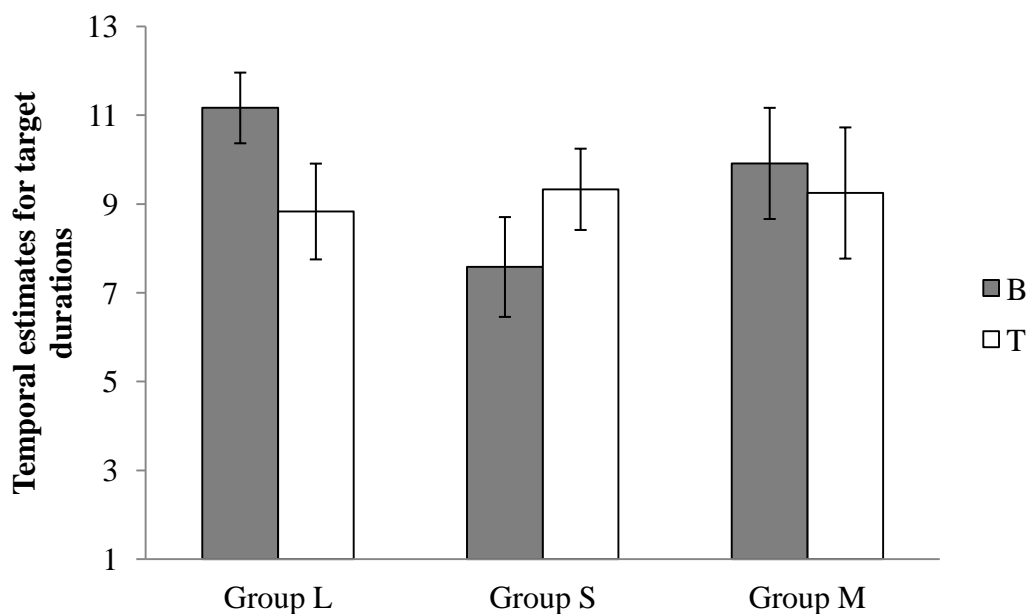

Figure 4.6. Mean temporal estimates for the blocking cue (B) and for the target cue (T) target durations per group. Error bars show ± 1 *SEM*.

4.2.3 Discussion

Overshadowing was found in all groups, thus duration of cues did not influence overshadowing. Blocking was observed in all three groups, hence blocking did not seem to be effected by cue duration. These findings disagree with some previous studies (Amundson & Miller, 2008; Gaioni, 1982; McMillan & Roberts, 2010). These studies found that changes in cue duration would influence responding to cue, which was not the case in the study described above. However the above findings do agree with Jennings and Kirkpatrick (2006) as they found that when stimulus (CS1) was longer or shorter than the reinforced stimulus (CS2), blocking was not stronger or weaker than in the control group.

The overshadowing cue and positive control cue means were the same for all groups, and temporal estimates for cues that were shown for 1900 ms were accurate. In addition, the coefficients of variance were very similar for overshadowing and positive control cues. Participants were not accurate at assessing the duration of the blocking cue in Group L, however there was no difference between the test durations for both blocking and target cues when comparing between groups. Furthermore, there was no difference in coefficients of variance for blocking and target cue which is in line with the SET (Gibbon, 1991) as this model predicts that coefficients of variance should remain the same, even when durations of cues differ. Overall, the results were consistent with data presented for animal studies where it was shown that rats accurately tracked CS durations despite the effects of cue competition on the CR (e.g. Gaioni, 1982; Jennings et al., 2007; Jennings & Kirkpatrick, 2006).

The results of this experiment have shown that cue duration effects in human causal learning have a negligible effect on cue competition. However, the difference in cue durations was rather limited at 25%; therefore, this relatively short difference in cue duration might not have been enough to effect cue competition and temporal estimates. A second experiment was therefore conducted. The rationale behind Experiment 4.2 was two-fold; the experiment was conducted firstly in order to determine the generality of the findings in Experiment 4.1. Secondly, Experiment 4.2 was conducted in order to assess the effects of increased differences in cue duration in both the overshadowing and blocking elements of the study (see also Jennings et al., 2007, Experiment 2).

4.3 Experiment 4.2

The next experiment was a direct replication of Experiment 4.1 with the exception that the difference in cue duration in the two experimental groups (Group S and L) was increased to 50% of that of the control group (Group M). Thus the ratio was increased to 1:1.5 in Group S and to 1.5:1 in Group L.

4.3.1 Methods

Participants

Thirty one participants were recruited, however the experiment crashed when one participants was tested, therefore this participant could not be included in data analyses. Ages ranged from 19 to 29 and three participants were between 42 and 51 (M = 23.30, SD =8.60). Twenty three of the participants were female and seven were male. Three participants were not native English speakers. Participants were randomly assigned to one of the three experimental groups (Group M: N = 9; Group S: N = 11; Group L: N = 10).

Stimuli

The stimuli used in the present experiment were identical to those of Experiment 4.1

Procedure

Experiment 4.2 was very similar to Experiment 4.1, except that the durations were shorter (950 instead of 1425 ms) and longer (2850 instead of 2375 ms) than the durations in Experiment 4.1. Three groups were tested in this experiment; Group L in which the blocking stimulus was longer (2375 ms) than the target stimulus (1900 ms), Group S in which the blocking stimulus was shorter (1425 ms) than the target stimulus (1900 ms), and Group M in which all stimuli were 1900 ms. See Table 4.3 for all stimulus durations for Group L and Group S. In this experiment all conditions were also counterbalanced.

Table 4.3. Duration of all stimuli for Group L and S. Letters in the top row represent blocking stimulus (B), target stimulus (T), overshadowing controls (O1 and O2), negative control (N), and positive control (C1 and C2).

	B	*T*	*O1*	*O2*	*N*	*C1*	*C2*
Group L	2850	1900	1900	2850	1900	1900	2850
Group S	950	1900	950	1900	1900	1900	950

In Experiment 4.2 the timing test durations depended on the stimulus duration in the training and testing phase. For example, in Group L when a stimulus was shown for 2850 ms during training and testing, in the timing test that stimulus would be shown for: 2375, 2612, 2850, 3088 and 3325 ms. See Table 4.4 for the timing test durations.

Table 4.4. Timing test durations for stimuli. Top row indicates training test duration of stimulus.

	2850	*950*	*1900*
1	2375	475	1425
2	2612	712	1662
3	2850	950	1900
4	3088	1188	2138
5	3325	1425	2375

Unfortunately, an error when programming the timing test in Group S resulted in participants being shown incorrect stimuli durations in the duration test of two of the stimuli, namely the two overshadowing stimuli. The first overshadowing stimulus (O1) was shown for 950 ms throughout training and testing, but in the timing test stimuli durations ranged from 1425 to 2375 ms. The second overshadowing stimulus (O2) was shown for 1900 ms during training and testing, whilst during the timing test stimuli durations ranged from 475 to 1425 ms.

4.3.2   *Results*

Overshadowing

Causality ratings for the two overshadowing cues were very similar; for the first overshadowing cue the mean was 7.37 (*SD*: 3.26), and for the second overshadowing cue was 6.10 (*SD*: 3.51). The causality ratings of the overshadowing cues were

submitted to a two Cue (O1 and O2) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. There was no main effect of Cue ($F(1, 27) = 1.57$, $p = 0.22$), no main effect of Group ($F < 1$) and no Cue x Group interaction ($F < 1$).

The two positive controls also received similar causality ratings with the first positive control having a mean causality rating of 9.77 (*SD*: 1.27) and the second control 9.67 (*SD*: 1.49). The causality ratings of the overshadowing cues were submitted to a two Cue (C1 and C2) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. The causality ratings for the two cues did not differ; there was no main effect of Cue ($F(1, 27) = 1.59$, $p = 0.22$). There was also no main effect of Group ($F(2, 27) = 1.11$, $p = 0.35$) and no Cue x Group interaction ($F(2, 27) = 1.67$, $p = 0.21$). These results indicated that the durations of the blocking cue did not influence the causality ratings, and the difference in duration between the blocking and target cue also did not influence causality ratings.

An ANOVA was conducted to test the difference between the mean of the two overshadowing cues and the mean of the two positive controls; the causality ratings were submitted to a two Cue (C and O) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. This showed a main effect of Cue ($F(1, 27) = 52.69$, $p < 0.001$), see Figure 4.7. There was no difference between groups; no main effect of Group ($F < 1$) and there was no Cue x Group interaction ($F(2, 27) = 1.16$, $p = 0.33$). Thus, there was overshadowing in this experiment and this was not affected by the overshadowing cue and positive control being different durations.
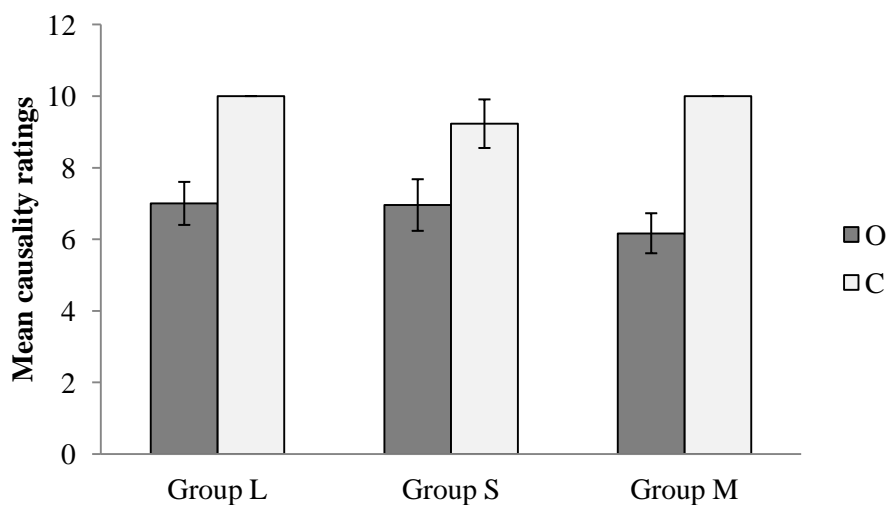
Figure 4.7. Mean causality ratings for the overshadowing cues (O) and positive controls (C) for Group L, S and M. Error bars show ±1 *SEM*.

Blocking

The mean blocking score for Group L and M were identical, see Figure 4.8 and for Group S was also comparable. A simple t-test showed the means differed from zero; Group L: $t(9) = 4.32$, $p < 0.01$, Group S: $t(10) = 2.50$, $p = 0.03$ and Group M: $t(8) = 3.70$, $p < 0.01$.

An ANOVA with Groups (L, S and M) as between-subjects factors tested whether there was a difference in blocking scores for the three groups. No main effect of Group was found ($F < 1$). Thus, the duration of the blocking stimulus compared to the durations of the target stimulus did not influence blocking.
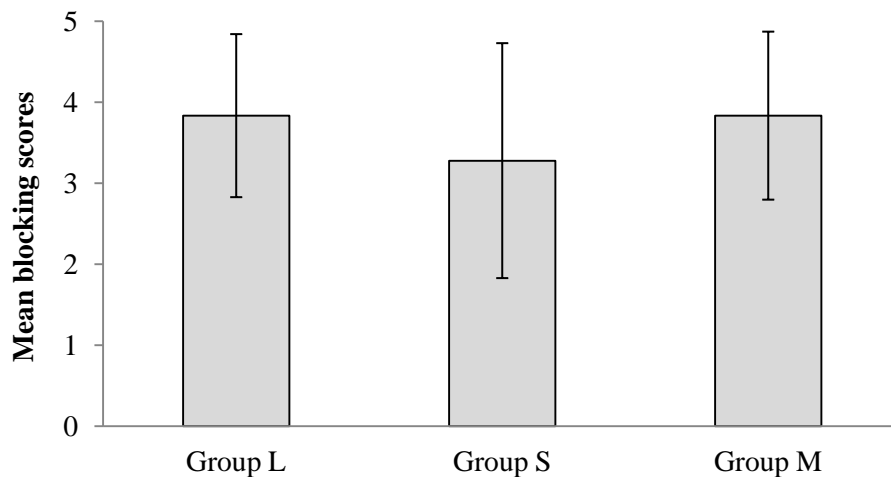
Figure 4.8. Mean blocking scores for Group L, S and M. Error bars show ±1 *SEM*.

Temporal estimation

Overshadowing & control cues

In Group L the mean for the second overshadowing cue (O2) and positive control (C2) (both 1900 ms) were higher than the first overshadowing cue (O1) and first positive control (C1) (both were 2375 ms), see Figure 4.9. The mean temporal estimate for O1 in Group L was lower than O2. The mean for O2 was higher than the expected mean (nine).
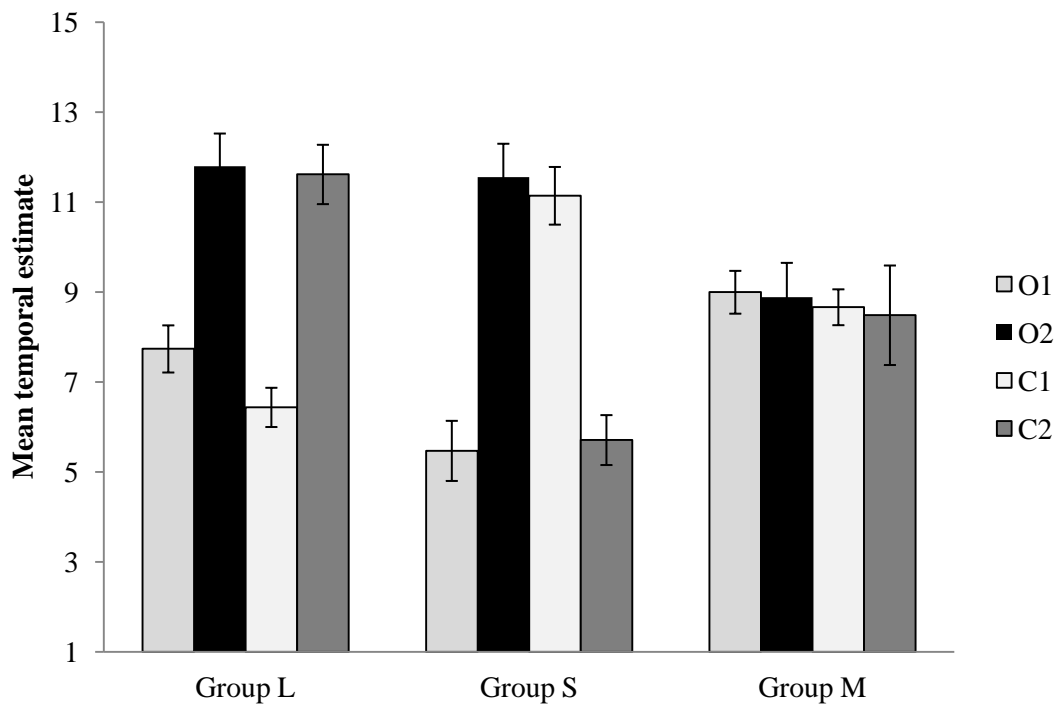
Figure 4.9. Mean temporal estimates for the two overshadowing cues (O1 and O2) and the two positive controls (C1 and C2) for Group L, S and M. Error bars show ±1 *SEM*.

An ANOVA looked at whether there was a difference between the mean temporal estimates for the two overshadowing cues and the two positive controls. The temporal estimates of the control cues were submitted to a four Cue (O1, O2, C1 and C2) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. There was a main effect of Cue (Greenhouse- Geisser: $F(2.30, 61.98) = 24.64$, $p < 0.001$), no main effect of Group ($F < 1$), therefore there was no difference between the groups, however there was a Cue x Group interaction ($F(4.59, 61.98) = 28.30$, $p < 0.001$).

The causality ratings of the control cues were submitted to a four Cue (O1, O2, C1 and C2) between-subjects ANOVA with both Cue as a factor. When comparing the means of temporal estimates for Group M only, there was no difference between the cues (main effect of Cue: $F < 1$). Hence, the difference between cues and the interaction is probably due to the varying durations of the overshadowing cues and positive controls in Group L and S.

The coefficients of variance (Figure 4.10) showed a similar trend to the mean temporal estimates. The coefficients were submitted to a four Cue (O1, O2, C1 and C2) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. In Group L there was greater variation for O1 and C1, whilst in

Group S there was greater variation for O1 and C2. An ANOVA showed a main effect of Cue ($F(3, 81) = 6.13$, $p = 0.001$), no main effect of Group ($F < 1$) and a Cue x Group interaction ($F(6, 81) = 8.74$, $p < 0.001$).

The coefficients of variance were analysed with a between- subjects ANOVA with four Cues (O1, O2, C1 and C2) as factors. However, when only analysing Group M, there was no difference in variance between cues; no main effect of Cue ($F < 1$). The results showed that cue durations influenced the coefficients of variance of the individual cues.
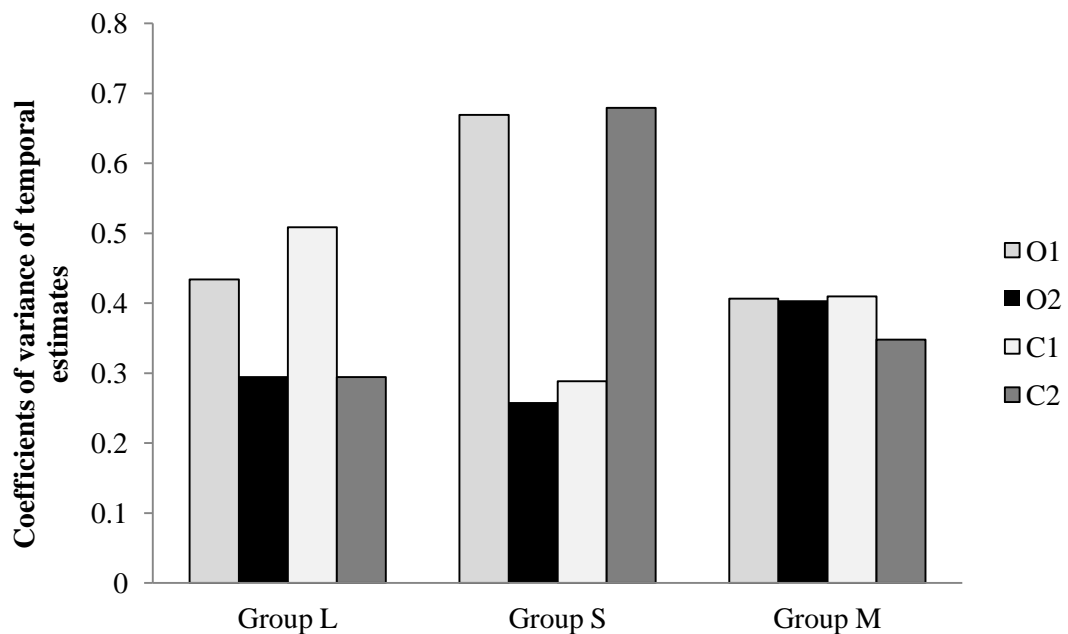
Figure 4.10. Mean coefficients of variance of temporal estimates for the two overshadowing cues (O1 and O2) and the two positive controls (C1 and C2) for Group L, S and M.

An analysis was also conducted on temporal estimates of the cues which were shown for the target duration, these were cue O1 and C1 in Group L, C1 in Group S and the mean of O1 and O2 and the mean of C1 and C2 in Group M. Estimates were compared for the 1900 ms test duration. The mean estimate for the overshadowing cue was 8.76 (SD: 2.01) and for the positive control was 7.69 (SD: 2.45). The estimates were submitted to a two Cue (O1 and C1) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. The analysis showed there was no main effect of Cue ($F(1, 17) = 2.33$, $p = 0.15$), no main effect of Group ($F(1, 17) = 1.77$, $p = 0.20$) and no Cue x Group interaction ($F < 1$).

Blocking & target cue

The temporal estimates for the different durations were compared with a within-subjects ANOVA with five Duration (75, 87.5, 100, 112.5, 125%) x three Group (L, S and M) with both Duration and Group as repeated measures. There was a main effect of Duration ($F(4, 108) = 22.25$, $p < 0.001$), see Figure 4.11. The temporal estimates for the three groups were 11.5 (*SD*: 4.25) for Group L, 5.38 (*SD*: 2.72) for Group S and 8.91 (*SD*: 2.81) for Group M. There was a difference between the mean estimates for the blocking cue between groups; there was a main effect of Group ($F(2, 27) = 19.67$, $p < 0.001$). There was no Duration x Group interaction ($F(8, 108) = 1.11$, $p = 0.36$). In every duration test the actual duration should be scored nine as the tests are specific for every cue duration, however, this was not the case. Therefore, the longer or shorter duration of the blocking cue influenced the mean estimates.
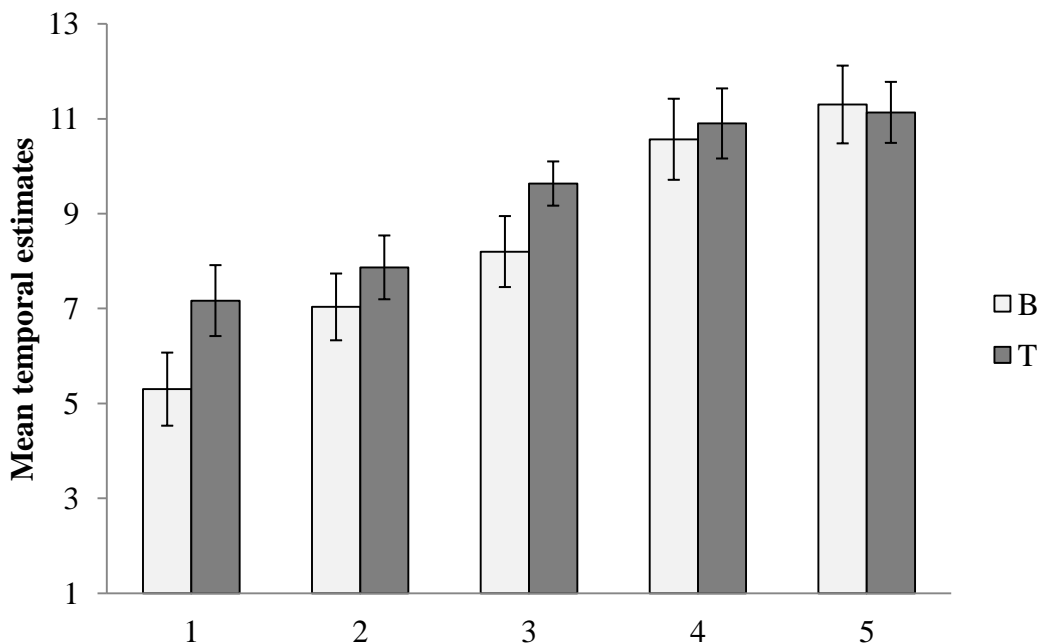
Figure 4.11. Mean temporal estimates for the blocking cue (B) and for the target cue (T) per test duration (1 to 5, 1 being the shortest duration tested, and 5 being the longest). Error bars indicate ± 1 *SEM*.

A similar trend was seen for the target cue, see Figure 4.14. The temporal estimates of the target cue were submitted to a five Duration (75, 87.5, 100, 112.5, 125%) x three Group (L, S and M) with both Duration and Group as repeated measures. Participants were accurate at distinguishing between the durations in the duration test; a main effect of Duration was observed ($F(4, 108) = 12.52$, $p < 0.001$). The temporal

estimates between groups varied; for Group S the mean was the highest with 11.31 (*SD*: 2.94), Group L and M had similar means with the former being 8.26 (*SD*: 3.33) and the latter being 8.13 (*SD*: 3.52). There was a main effect of Group ($F(2, 27) = 7.22, p < 0.01$) and there was no Duration x Group interaction ($F(8, 108) = 1.35, p = 0.23$). Therefore, the duration of the blocking and other cues influenced the target cue estimates.

Coefficients of variance for temporal estimates for blocking and target cue per group ranged from 0.31 to 0.65, see Figure 4.12. The variance for the blocking cue was much higher in Group L than in Group L and M, and the variance for the target cue was lower for Group S than Group L and M. The blocking cue had a mean coefficient of variance of 0.48 and the target cue of 0.34. The coefficients of variance were submitted to a two Cue (B and T) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. A main effect of Cue ($F(1, 27) = 7.99, p = 0.01$) was observed. Therefore, there was a difference in variance between the blocking and target cue. There was no main effect of Group ($F(2, 27) = 1.21, p = 0.31$), however there was a Cue x Group interaction ($F(2, 27) = 12.94, p < 0.001$). By looking at the results it could be concluded that when the blocking cue was of a shorter duration than the target cue, there was more variance for the blocking cue temporal estimates.
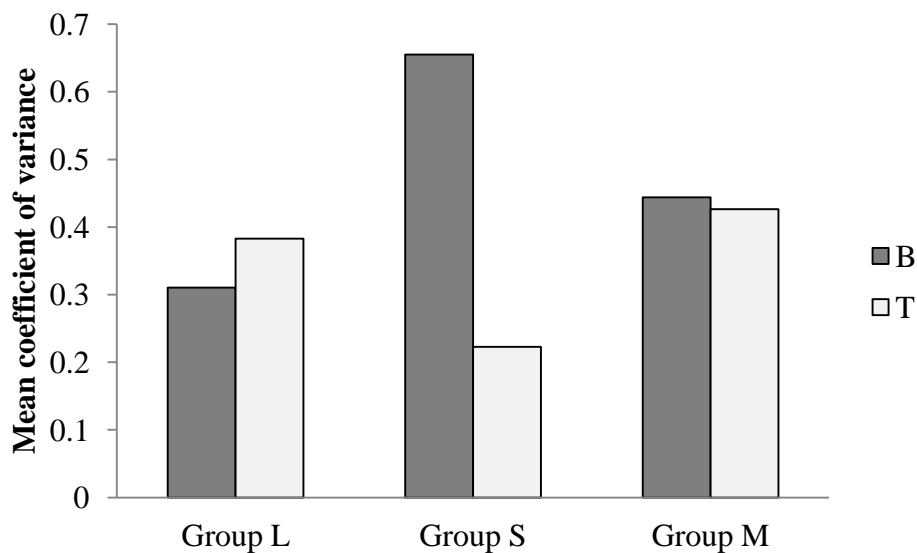
Figure 4.12. Mean coefficients of variance for the blocking cue (B) and for the target cue (T) for Group L, S and M.

To test whether participants were correct at making temporal estimates, the target durations for the blocking and target cue were compared to nine in the three

groups with a t-test, see Table 4.5. The temporal estimates for the target duration for the blocking cue were different from nine, for the target cue in Group S, however, temporal estimates were accurate for both cues in Group L and M. Therefore, the shorter duration of the blocking cue in Group S influenced participants' ability to accurately assess the cue duration.

Table 4.5. T-tests comparing target duration estimates of blocking (B) and target cue (T) in Group L, S and M to nine.

Group	Cue	t	df	p
L	B	1.62	9	0.14
L	T	0.87	9	0.40
S	B	-4.20	10	< 0.001
S	T	2.01	10	0.07
M	B	-1.95	8	0.09
M	T	-0.48	8	0.65

The target duration temporal estimates for blocking and target cue, see Figure 4.13, were also analysed. The estimates were submitted to a two Cue (B and T) x three Group (L, S and M) within-subjects ANOVA with both Cue and Group as repeated measures. The ANOVA showed there was no difference between cues as there was no main effect of Cue ($F(1, 27) = 3.33$, $p = 0.08$). A main effect of Group ($F(2, 27) = 3.85$, $p = 0.03$) was found, and an interaction between Cue x Group was also found ($F(2, 27) = 9.19$, $p < 0.01$). Therefore, the different durations of the blocking stimulus in Groups L and S influenced the target duration estimates.
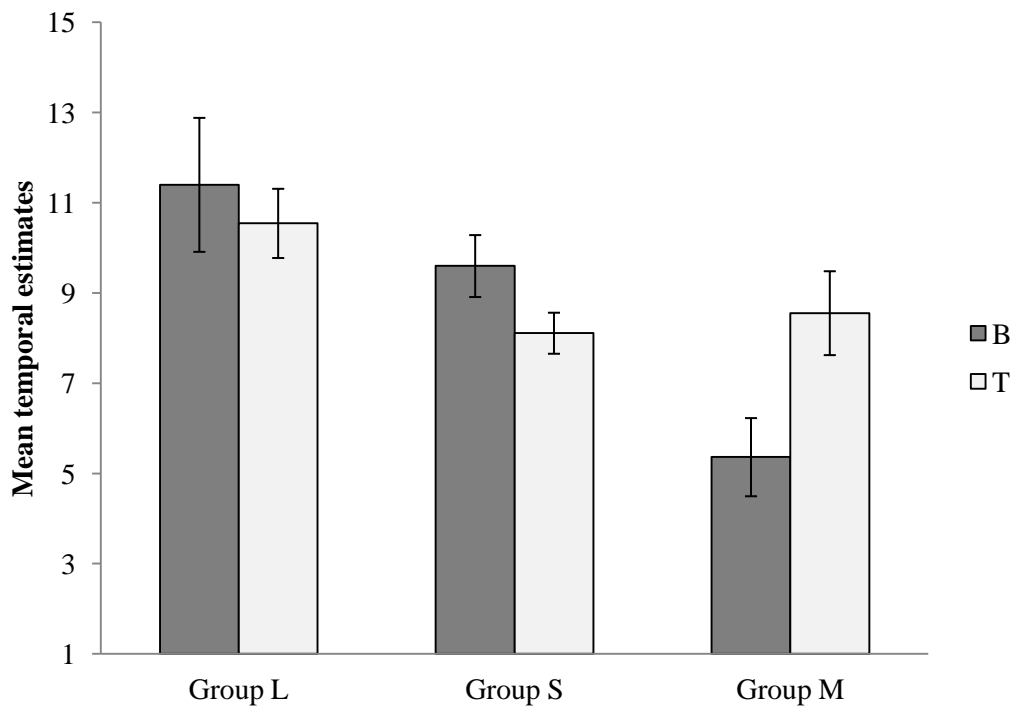
Figure 4.13. Mean temporal estimates for target durations for the blocking cue (B) and for the target cue (T) per group. Error bars indicate ± 1 *SEM*.

4.3.3   Discussion

The blocking and overshadowing results were very similar to Experiment 4.1. There was significant blocking and overshadowing in all three groups, hence the different durations of the blocking cue compared to the target cue did not influence cue competition. Furthermore, there did not seem to be any evidence of overall blocking and overshadowing levels differing between Experiment 4.1 and 4.2 (casual observation), thus the changes in durations from 1425 to 950 ms did not seem to influence blocking and overshadowing strength.

Increasing the temporal difference between the blocking and target cue did influence the temporal estimates of the two overshadowing cues, the positive controls, the blocking and the target cue which was not the case in Experiment 4.1. For example, for Group L the mean for the second overshadowing cue and positive control were higher than first overshadowing and positive control cue. Therefore, the different durations influenced temporal estimates. In Experiment 4.2 coefficients of variance differed between groups, yet this was not the case in Experiment 4.1. In this experiment, cues with shorter durations (blocking cue, Group S) showed greater variance, which is not in line with Weber's Law, which states that the coefficient of variance is constant

(Church, 2003; Gibbon, 1977). The overestimates and underestimates of the durations were not in line with SET (Gibbon, 1991).

4.4   General discussion

There was no effect of cue duration on causality ratings in either overshadowing or blocking and the results for blocking and overshadowing were very consistent across all experiments. The findings of Experiment 4.1 and Experiment 4.2 show no difference in blocking and overshadowing between the three different groups, thus, are not in line with previous animal literature. The majority of these studies found a difference in responding (for blocking and overshadowing) when durations of the blocking or target stimulus were longer or shorter (Jennings & Kirkpatrick, 2006; Urushihara & Miller, 2007). For example, Amundson and Miller (2008) changed trace intervals of stimuli in one training phase, which influenced blocking when comparing blocking in that training phase to the second training phase. The results described above are also not in line with Jennings & Kirkpatrick (2006) as they also found when stimulus (CS1) was longer or shorter than the reinforced stimulus (CS2), CS2 was blocked, but when CS1 was shorter than CS2, CS2 was not blocked. In the results described above, both the longer and shorter CS1 blocked CS2.

The procedure of the experiments in this chapter were similar to the rat study by Jennings et al. (2007), as like in Jennings et al. (2007) there were three groups, one in which the cues were not matched in durations and CS1 was longer than CS2, and one group in which cue duration was not matched but CS1 was shorter than CS2. In the third group durations were matched. The overshadowing results were partly in line with Jennings et al. (2007) as attenuated responding was not found. However, causality ratings did not differ between Group S compared to Group L, which was the case in their study.

It is possible that no difference in blocking was found because the stimulus durations did not differ enough in each group. In Jennings and Kirkpartick (2006) the duration of the target stimulus was nine times longer than the blocking stimulus; CS1 was presented for 10s and CS2 for 90s. In the above described experiments the blocking stimulus durations were only a quarter or half as long as the target stimulus duration. Therefore, it could be that instead of stimulus durations of 950 ms and 1900 ms, durations such as 500 and 4000 ms needed to be used to see an influence of stimulus duration on blocking.

The blocking and overshadowing results were in line with Macktinosh (1975) and Pearce Hall (1980) predictions as no difference was found between groups for blocking and overshadowing. These models do not take the duration of the stimulus into account, and thus, the models do not predict a difference in blocking or overshadowing between groups in which blocking stimulus is longer than target stimulus, or vice versa, compared to groups in which durations are matched for target and blocking cue. Therefore, the associative learning models were able to predict cue competition in the experiments described above.

In addition, the RW model (Rescorla & Wagner, 1972) could have also predicted associative strength in the above experiments. In Experiment 4.1 and 4.2 the ITIs were the same, but the cue durations were not – the RW model would predict less learning about the longer cue relative to the shorter cue in this circumstance (Rescorla & Wagner, 1972). This is because when the ITI duration is the same, a shorter CS (relative to the ITI) will give less extinction to context than with a longer CS. Thus, shorter CSs promote learning. Equal levels of blocking and overshadowing were found in all groups, thus the experimental results did not support the RW model.

There was no variation in temporal estimates for Experiment 4.1, however in Experiment 4.2 participants' estimates were different when comparing groups. Thus, the different durations of the blocking cue compared to the target cue influenced temporal estimates. There could be several explanations for this. Participants might have compared the duration of the first overshadowing cue to the second overshadowing cue, which caused them to overestimate the first and underestimate the latter in Group L. The same trend could be seen in Group S for the positive controls (but reversed as the shorter cue was the second positive control and the longer cue was the first overshadowing control).

The temporal estimate results in Experiment 4.2 could also be evidence of generalisation (Swanton, Gooch, & Matell, 2009; Wearden, 1992; Wearden & Lejeune, 2008; Wright, Buonomano, Mahncke, & Merzenich, 1997). For example, in Swanton et al. (2009) food was made available at a shorter (10s) or longer (20s) interval. However, when the rats were tested, they showed a peak response at an interval which was the mean of the two intervals. This is what participants could have done in Experiment 4.2 as participants underestimated cues with target durations (1900 ms) and overestimated cues which were longer or shorter than the target duration. Thus, participants probably generalized between durations.

There was a difference between groups for Experiment 4.2 in coefficients of variance, hence, the experimental results were not in line with predictions made by the SET model (Gibbon, 1977, 1991). The SET model predicts that the coefficients of variance should not differ between cues of different durations, as Weber's Law hypothesises that the coefficient of variance remains the same (Church, 2003; Gibbon, 1977, 1991). Thus, when the mean temporal estimate increases, the standard deviation should also increase (Church, 2003).

To conclude, the present chapter presented two studies on the effects of cue duration on causal learning. There is a level of consistency between human and animal causality rating tasks and results. Previous animal research which has tested influence of stimulus durations has shown that in a difference in cue duration did not change levels of overshadowing in animals (Jennings et al., 2007; McMillan & Roberts, 2010), which was the same as the results discussed above. However, animal studies have shown that stimulus duration effects can have a profound effect on CR to the target (Jennings & Kirkpatrick, 2006). The present study has shown that this is not the case in human learning. Finally, the results concerning cue competition and temporal estimates of cue duration indicate that temporal estimates and cue competition were relatively independent and, consequently, different theoretical approaches are required in order to account for them.

Chapter 5. Spatial distance between cues does not affect cue duration during causal learning

5.1   Introduction

Spatial learning experiments often test how quickly participants and subjects find a hidden goal relative to positions of nearby cues (Hayward, McGregor, Good, & Pearce, 2003). In addition, spatial learning experiments have also demonstrated cue competition effects, suggesting that these types of tasks are amenable to associative theorising (for review see Chamizo, 2003). In the field of human learning it has been shown that associative principles apply to human spatial learning tasks (Chamizo, Aznar-Casanova, & Artigas, 2003; Prados, 2011; Redhead & Hamilton, 2009).

Several studies have provided evidence that the design of the experiment not only influences processing of cues, but also blocking (Glautier, 2002; Martin & Levey, 1991). The studies found weaker blocking as a consequence of smaller distance between cues (compared to blocking strength when cues were further apart), though they did not always infer this was because of the type of processing. Martin and Levey (1991) conducted an eyelid conditioning experiment where CSs were coloured squares and USs were eye puffs. They found that when blocking and target cue were presented close together, weaker blocking was observed than when the two cues were separated by a different cue. Glautier (2002) conducted a similar study which used a game card setup; the cues could either both be on the same card or on separate cards. He found that when cues were further apart (both on a separate card), blocking was stronger than when cues were presented closer together on the same card.

Livesey and Boakes (2004) also investigated whether distance between cues would affect the magnitude of blocking. They presented two experiments in which they tested effect of distance between cues (second experiment), and also grouping of cues (third experiment) on cue competition. Thus, in the second experiment two conditions were tested; one in which cues were presented close to each other and a second in which cues were distant from each other. The third experiment also tested two conditions; the first condition showed two cues that were part of same unit and the second condition showed cues on separate units and at a distance from each other. Livesey and Boakes (2004) found no blocking in conditions in which the cues were part of one unit (clearly grouped), no blocking in the conditions in which cues were side by side but they did find blocking in conditions in which cues were further apart.

An animal study by Amundson and Miller (2007) has also investigated the effect of distance between cues on associative strength. Amundson and Miller (2007) conducted a rat lick suppression study in which they saw higher blocking scores in the condition in which both cues (blocking and target cue) originated from the same spatial location. Therefore, this animal study gave opposite results to those found by Glautier (2002) and Martin and Levey (1991) in humans.

Distance between cues (Amundson & Miller, 2007; Glautier, 2002; Martin & Levey, 1991) or grouping of cues (Thorwart & Lachnit, 2009) could determine whether or not cues are processed configurally (i.e. as a whole, as described in the configural model for example: Pearce, 1987, 1994) or elementally (as seperate units, described in the following models: Harris, 2006; Mackintosh, 1975b; Pearce & Hall, 1980; Rescorla & Wagner, 1972; Wagner, 2003). Glautier (2002) and Martin and Levey (1991) rationalised that during the compound phase participants processed the cues in a configural manner because their relative proximity led to the perception that the cues represented a single unit and participants processed them configurally (as a whole). Livesey and Boakes (2004) hypothesised that blocking would be weaker when cues were presented closer together as this would lead to configural processing.

The examples described above show that depending on location of stimuli in relation to each other cues are processed elementally or configurally and this affects the magnitude of cue competition. More specifically, the distance between cues effects processing and cue competition. Thus, the two experiments in this chapter were set up to test whether distance between cues and grouping of cues would influence blocking and overshadowing. Firstly, it was predicted that blocking would be stronger in groups where target and blocking cue were presented further apart, as they would be processed elementally, as supported by the RW model (Rescorla & Wagner, 1972). Furthermore, it was predicted that cues would be processed configurally when cues were presented close together, and that blocking would be weaker in these groups. This is supported by the configural model (Pearce, 1987, 1994) and this model predicts that overshadowing is weaker in the group in which cues are closer together, seeing that there is more generalization between the two cues when they are more similar (because the location of the cues is similar).

Additionally, the second question of interest in the present series of studies addressed whether the physical location of cues relative to each other would affect temporal estimates of cue duration. The kappa effect formulised by Cohen, Hansel, and Sylvester (1953) stated that intervals with cues that were physically shown further apart

would be rated as longer (in duration) than stimuli closer together. Therefore, if the kappa effect would influence temporal estimates in this setup, participants would overestimate compound cue durations when they were further apart than when they were closer together.

Roussel, Grondin, and Killeen (2009) and Collyer (1977) also studied influence of spatial factors on interval estimates. In the study by Roussel et al. (2009) participants were shown long or short durations, and had to indicate whether they were long or short. Roussel et al. (2009) found that durations were perceived as longer if a fixation point was shown higher on screen than in the middle. Collyer (1977) presented participants with stimulus patterns with different spatial and temporal intervals and asked participants to determine the interval (both spatial and temporal). Collyer (1977) found that participants combined spatial and temporal stimulus information, thus from this it can also be suggested that spatial location influences temporal estimates. However, the aforementioned studies looked at interval presentation, which was not the case in the experiments described below.

Presuming the locations of the blocking and target cues relative to each other affect how the learning process is instantiated, we might then assume that this will have a direct influence on the accuracy of temporal estimates of cue duration. Specifically, if cue competition is subject to an elemental process then the accuracy of temporal estimation of the target cue should be attenuated; if the cues are learned about following a configural rule then no attenuation of temporal estimation of the target cue (relative to the pre-trained blocking cue) should be observed. This latter assumption is complicated by the fact that standard timing models would not predict any difference in temporal estimates, albeit for completely different reasons; for example, predictions following SET (Gibbon, 1991) would not result in any difference in temporal estimates or standard deviations between compound cues as the cues were the same duration and the same modality.

5.2   Experiment 5.1

The present experiment tested whether distance between cues would affect the magnitude of overshadowing and blocking. It was predicted that if blocking was stronger in the groups in which cues are further apart, elemental processing is supported (Rescorla & Wagner, 1972), however, if blocking was weaker, this would support configural processing (Pearce, 1987, 1994). Furthermore, the temporal estimates of

participants were also investigated in order to determine whether there was a decline in accuracy of temporal estimates related to cue proximity. Consequently, in the experiment described below, cues were presented in two rows on a computer monitor; one row was located along the top of the monitor while the second row was located along the bottom of the monitor. There were two experimental groups; one in which blocking and target cue were on same row (Group SR), and a second group in which target and blocking cue were on different rows (Group DR).

5.2.1   Methods

Participants

In total twenty three participants took part in this study; thirteen participants were female, ten were male. Their ages ranged between 19 and 59 years old (*M*: 26.17, *SD*: 8.85). Six participants were not native English speakers and 17 were native English speakers. Twelve participants were tested in Group SR and 11 in Group DR. As in previous experiments, participants were paid £4 as a thank you upon completing the task.

Stimuli and apparatus

The stimuli set used in this experiment was identical to the one used in Experiment 4.2, see Figure 5.1. Participants were shown ten lightning machine buttons; eight buttons were stimuli and two were 'dummy' lightning machine buttons that were white (or 'off') throughout training and testing. This enabled stimuli to be presented at equal distances and never directly at adjoining locations. Cues measured 3 (height) by 3.3 (width) cm and were shown with a 1.9 cm gap between cues. The far left cue was presented 10.1 cm from the left edge of the monitor, and 2.4 cm from the top of the monitor. The USs (lightning bolts) measured 14.5 by 2.5 cm and was shown in the middle of the monitor.
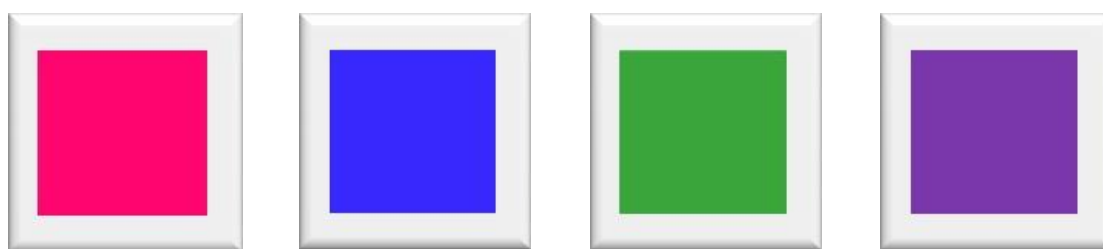
Figure 5.1. Example of stimuli used in Experiment 5.1 and 5.2.

All stimuli were presented on one monitor. There were ten possible stimulus locations- five along the top of a Dell 19" monitor and five along cue the bottom of the monitor (see fig 5.2a and 5.2b for screenshots). When blocking and target cue were on the same row, they were 15 cm apart and when they were on different rows they were 22.5 or 24.5 cm apart.
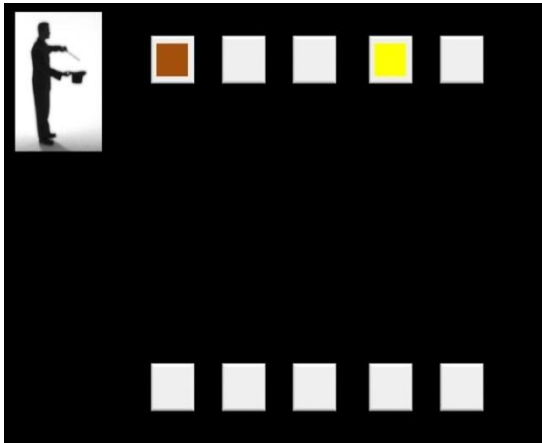
Figure 5.2a. Example of compound cue presentation for Experiment 5.1.
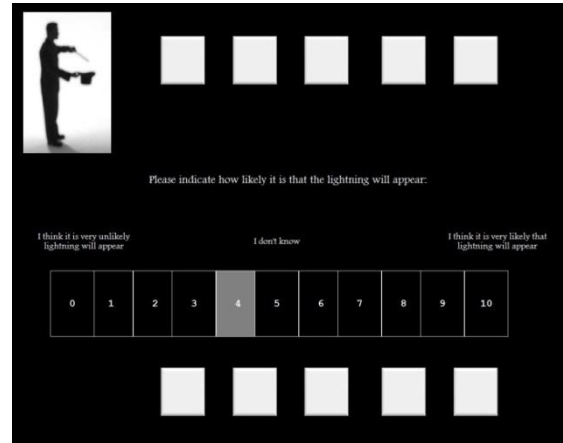
Figure 5.2b. Example of prediction screen with score '4' highlighted for Experiment 5.1.

Procedure

All experimental procedures were the same as those described previously with the following exceptions; participants were asked to estimate whether the test duration was longer or shorter than the target duration (the duration of the cue shown during training); each cue was presented five times and each presentation differed in duration (1425, 1663, 1900, 2138 and 2375 ms).

5.2.2   *Results*

Overshadowing

The causality ratings of the control cues were submitted to a two Cue (C1 and C2) between-subjects ANOVA with Cue as a factor. Both overshadowing cues received a similar rating (O1 and O2) ($F(1, 44) = 0.03$, $p = 0.86$). Furthermore, there was no difference in ratings between the two groups (SR and DR) ($F(1\ 42) = 0.02$, $p = 0.90$) and no Group x Overshadowing Cue interaction ($F(1, 42) = 0.01$, $p = 0.94$). Therefore,

the mean of the causality ratings for both overshadowing cues was used in the subsequent analysis.

Participants gave the control cues a maximum causality rating in both groups, and the overshadowing controls were rated somewhat lower (Figure 5.3). The causality ratings of the control cues were submitted to a two Cue (C and O) x two Group (SR and DR) within-subjects ANOVA with both Cue and Group as repeated measures. There was a difference between causality ratings for the mean rating awarded to the overshadowing cues and the control ($F(1, 21) = 77.24$, $p < 0.01$). Therefore, the magnitude of the overshadowing effect was similar irrespective of the physical distance between the overshadowing cues.
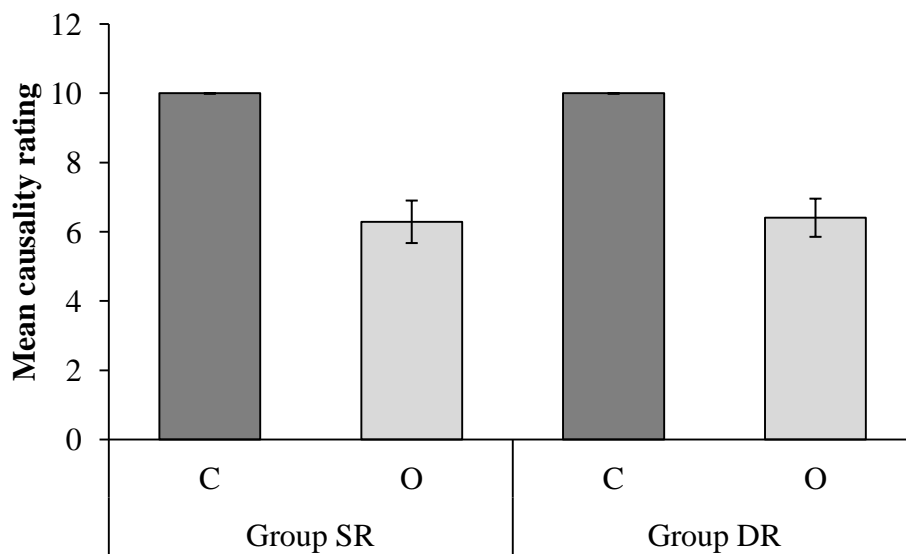
Figure 5.3. Mean causality ratings for both overshadowing cues (O) and control cues (C) for both groups (SR and DR). Error bars show ±1 *SEM*.

Blocking

Blocking was observed in both groups: Group SR, $t(11) = 2.54$, $p = 0.03$ and Group DR, $t(10) = 3.24$, $p < 0.01$, see figure 5.4. There was no difference in the magnitude of the blocking effect across the two groups (SR vs. DR); $t(21) = -0.44$, $p = 0.66$.
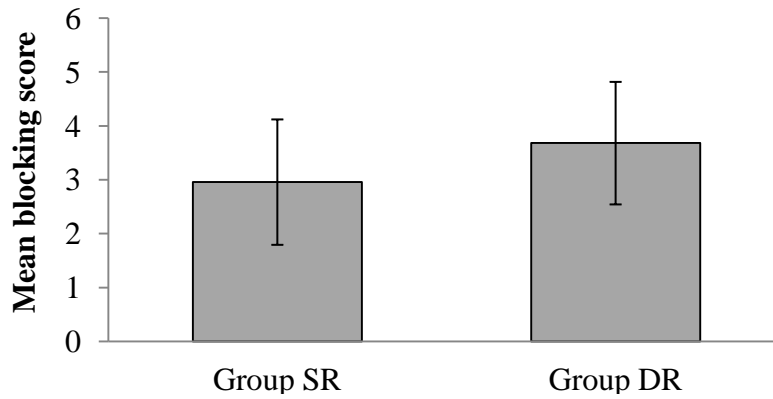
Figure 5.4: Mean blocking scores per group. Error bars show ±1 *SEM*.

Temporal Estimation

Overshadowing & control cues

A comparison of the temporal estimates of the target duration for the two overshadowing cues in Group SR indicated that they did not differ from a mean of five (O1: $t(11) = 0.80$, $p = 0.44$ and O2: $t(11) = -1.60$, $p = 0.14$, Figure 5.5). However, for Group DR, the mean estimates for the two cues did differ from five (O1: $t(10) = 2.68$, $p = 0.02$ and O2: $t(10) = -2.96$, $p = 0.01$) indicating that participants were less accurate at temporal estimates in the group in which the two overshadowing cues were on separate rows, and there was a greater distance between them.
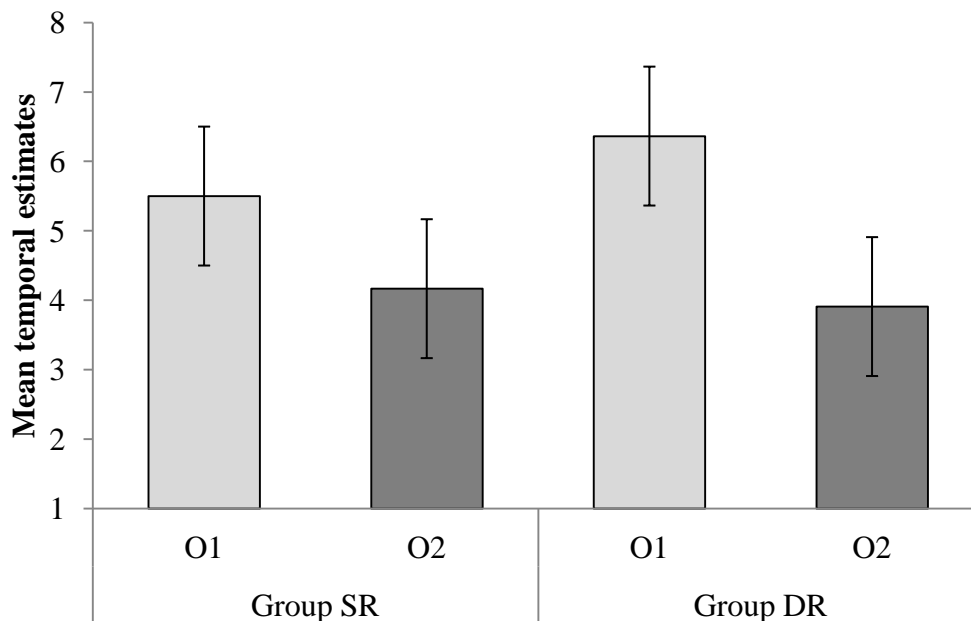
Figure 5.5. Mean temporal estimates for the two overshadowing cues (O1 and O2) for Groups SR and DR. Error bars show ±1 *SEM*.

The temporal estimates for 1900 ms (target duration) of the control cues were submitted to a two Cue (C1 and C2) x two Group (SR and DR) within-subjects ANOVA with both Cue and Group as repeated measures. The ANOVA revealed there was a difference between temporal estimates for the target duration between the two overshadowing cues (Cue: $F(1,21) = 15.52$, $p = 0.001$) and when comparing Group SR and DR there was no difference ($F < 1$). There was no Group x Cue interaction ($F(1, 21) = 1.36$, $p = 0.26$). Therefore, although there was a clear effect of treatment on temporal estimates, this was probably because all participants made errors in the same direction (see Figure 5.5) and therefore the magnitude of the error did not differ across the two experimental groups.

The temporal estimates for the control cue of the target duration were also analysed. The estimates were different from five for Group SR ($M = 3.83$, $SD = 1.47$); $t(11) = -2.76$, $p = 0.02$, however estimates were not different from five in Group DR ($M = 4.27$, $SD = 1.68$); $t(10) = -1.44$, $p = 0.18$). An independent t-test investigating the estimates of the control cue showed that there was no difference between target duration estimates in both groups ($t(21) = -0.67$, $p = 0.51$).

The estimates for the two overshadowing cues were compared against the control cue collapsed across the five probe durations (i.e. mean of all five duration estimates was calculated). The temporal estimates of the overshadowing and control cues were submitted to a three Cue (O1, O2 and C) x two Group (SR and DR) within-subjects ANOVA with both Cue and Group as repeated measures. An ANOVA across the three cues indicated that the estimates did not differ (no main effect of Cue: $F(1,42) = 1.56$, $p = 0.22$). In addition, there was no main effect of Group ($F < 1$) and no Cue x Group interaction ($F < 1$, see Figure 5.6).
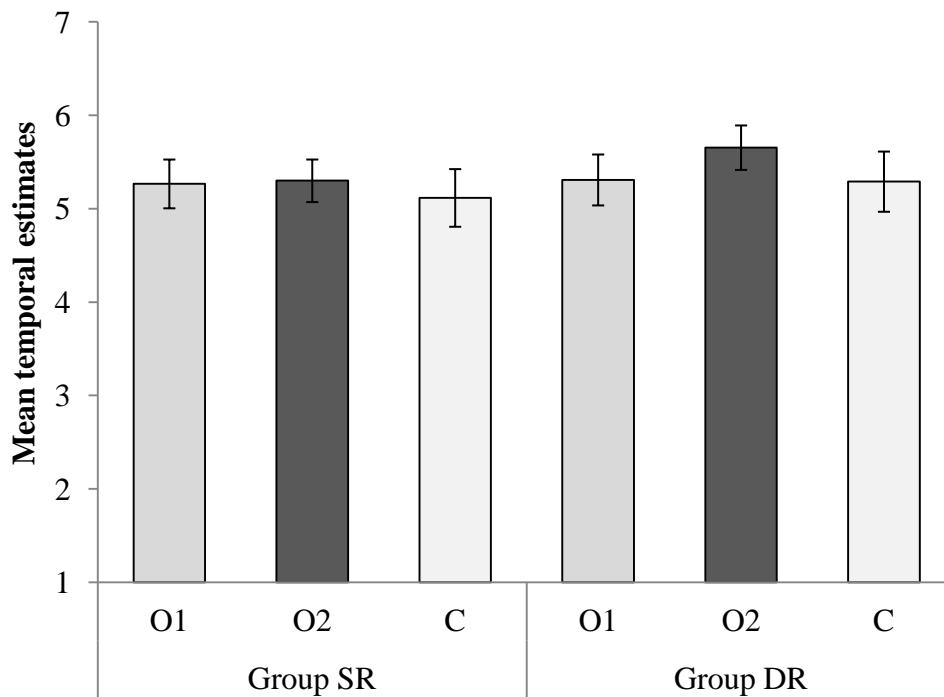
Figure 5.6. Mean temporal estimates for the two overshadowing cues (O1 and O2) and the control (C) in both groups (SR and DR). Error bars show ±1 *SEM*.

Furthermore, standard deviations of the mean temporal estimates of the overshadowing and control cues were submitted to a three Cue (O1, O2 and C) x two Group (SR and DR) within-subjects ANOVA with both Cue and Group as repeated measures. The comparison of the standard deviations between the three cues did not reveal any differences across cue estimates (Cue; $F < 1$) and there was no difference between Groups ($F(1, 21) = 1.10$, $p = 0.31$). There was no interaction between the Cue x Group ($F < 1$). Standard deviations for Group SR were O1: 1.77, O2: 1.56, C: 1.67 and standard deviations for Group DR were O1: 2.00, O2: 1.91 and C: 1.95). Together, these results show that there was a difference in temporal estimates between the two overshadowing cues, but no difference between the overshadowing cues and the control.

Blocking & Target cue

The temporal estimates of the blocking cue were submitted to a five Duration (1425, 1663, 1900, 2138 and 2375 ms) x two Group (SR and DR) within-subjects ANOVA with both Duration and Group as repeated measures. An ANOVA compared the temporal estimates for the blocking cue. This showed there was a difference between estimates of the five test durations ($F(4, 84) = 18.33$, $p < 0.001$, see Figure 5.7). There was no main effect of Group ($F(1, 21) = 1.25$, $p = 0.28$) and there was no interaction between Duration x Group ($F(4, 84) = 1.05$, $p = 0.39$).

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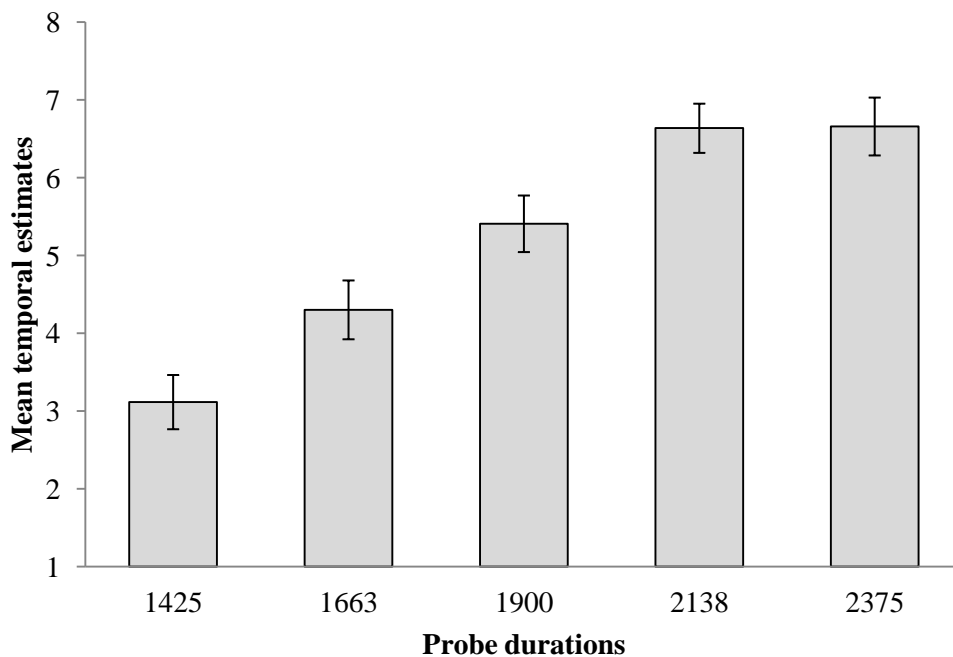
Figure 5.7. Mean temporal estimates for blocking cue for test durations. Durations were in milliseconds. Temporal estimates were on a Likert scale ranging from one (shorter) to nine (longer). Error bars show ±1 *SEM*.

When collapsing the five test duration estimates, there was no difference in standard deviation for the temporal estimates between the two groups for the blocking cue ($t(21) = -1.65$, $p = 0.11$).

The temporal estimates for the target cue were similar in the two groups (Group SR *M*: 5.15 and *SD*: 1.50, Group DR *M*: 5.38 and *SD*: 2.03) and analysis showed there was no difference in standard deviations of the target cue between groups ($t(21) = -1.47$, $p = 0.16$).

The temporal estimates of the target cue were submitted to a five Duration (1425, 1663, 1900, 2138 and 2375 ms) x two Group (SR and DR) within-subjects ANOVA with both Duration and Group as repeated measures. There was a difference in the temporal estimates for the target cue for the five different probe durations ($F(4, 84) = 24.31$, $p < 0.001$) yet there was no main effect of Group ($F < 1$) and there was no interaction between Duration x Group ($F(4, 84) = 1.24$, $p = 0.30$).

The standard deviations of temporal estimates of the blocking and target cue were submitted to a Cue (B and T) x two Group (SR and DR) within-subjects ANOVA with both Cue and Group as repeated measures. For the blocking and target cues, the analysis showed that the standard deviation did not differ between the blocking and target cue (ANOVA $F(1, 42) = 1.22$, $p = 0.28$) for the temporal estimates. However,

standard deviations did differ between groups (main effect of Group: $F(1, 42) = 4.88$, $p = 0.03$), see Figure 5.8. There was no Group x Cue interaction ($F < 1$).
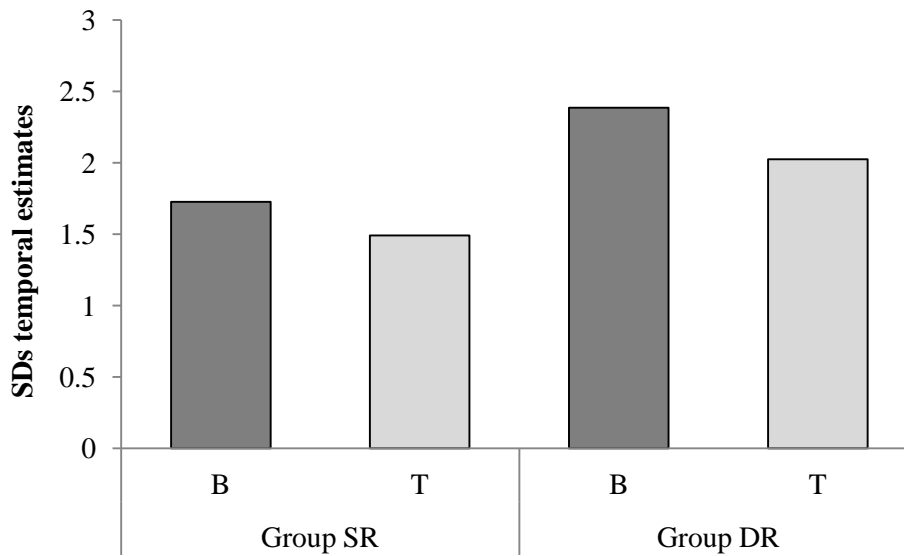
Figure 5.8. Standard deviations of mean temporal estimates for the blocking (B) and target cue (B) in both groups (SR and DR).

A one sample t-test showed that temporal estimates for the target duration for the blocking cue did not differ from five for either group (SR: $t(11) <0.001$, $p =1$ and DR: $t(10) =1.77$, $p =0.11$). Though, the temporal estimates of the target duration for the target cue did differ from five in both groups (SR: $t(11) = 4.71$, $p < 0.01$ and DR: $t(10) = 3.32$, $p < 0.01$).

The temporal estimates of target duration for the blocking and target cue were submitted to a Cue (B and T) x two Group (SR and DR) within-subjects ANOVA with both Cue and Group as repeated measures. There was a difference in temporal estimates when comparing the blocking and the target cue for the target duration (1900 ms); $F(1, 21) = 9.54$, $p <0.01$, see Figure 5.9. There was no Cue x Group interaction ($F < 1$) and there was no effect of Group ($F(1, 21) = 1.31$, $p = 0.27$). The above results show that people were more accurate at temporal estimates for the blocking cue, than the target cue.
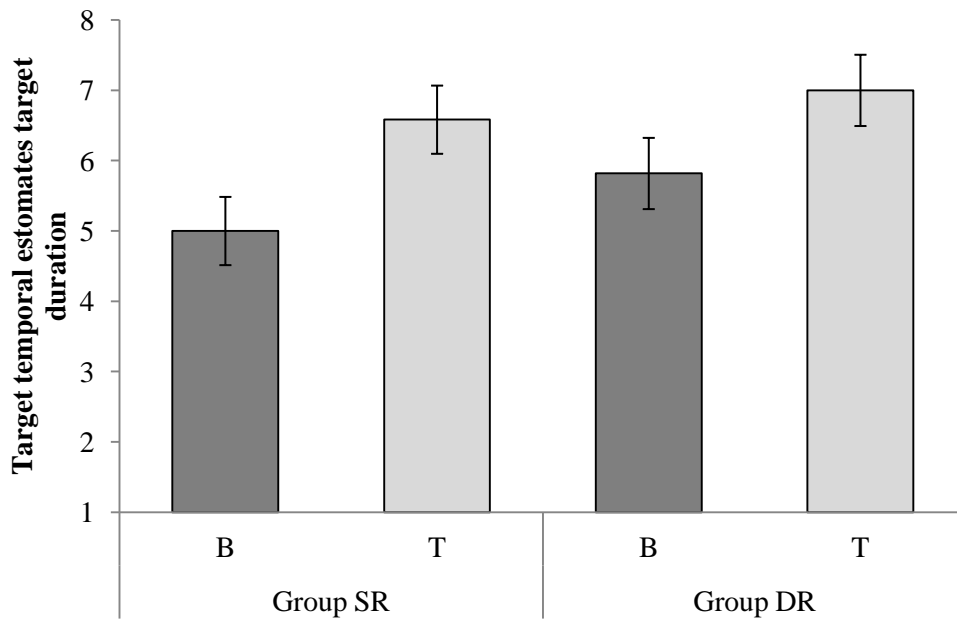
Figure 5.9. Temporal estimates for blocking (B) and target (T) cue for the target duration for the Group SR and DR. Error bars show ±1 *SEM*.

The analysis of temporal estimates showed that there was a difference in temporal estimates between the blocking and the target cue; participants overestimated the durations for the target cue. To conclude, the distance between the blocking and target cues did not influence temporal estimates.

5.2.3 Discussion

Blocking and overshadowing was evident in both groups and there was no difference between groups for blocking scores and overshadowing levels. Thus, the magnitude of the cue competition effect was not influenced by proximity of the cues to each other, or their location on the screen. In empirical terms, the results concerning cue competition are similar to findings by Thorwart and Lachnit (2009). The results presented here are not consistent with other investigations into the effects of cue proximity; for example, several studies have shown weaker blocking when cues are adjacent to each other than when presented further apart (see Glautier, 2002; Livesey & Boakes, 2004; Martin & Levey, 1991).

The temporal estimation results (for means of estimates) showed that participants were accurate at assessing most durations. Participants were accurate at estimating durations for one of the overshadowing cues, the target and the blocking cue. When comparing compound cues differences in temporal estimates were found; the two overshadowing cues estimates varied, as did the blocking and target cue estimates. For

example, participants overestimated the durations for the target cue, but they accurately estimated the blocking cue. There were no differences between groups when comparing the overshadowing cues with the control cue estimates and the blocking with the target cue estimates. Hence, the distance between the cues did not have any significant effect on participants' temporal estimates.

In the present experiment cues were shown on a single computer monitor. It is possible however, that by creating a larger viewing area that we might see an effect of cue proximity on cue competition. For example, in the study conducted by Glautier (2002), cues were presented on different playing cards, clearly physically separating the cues. To test this, we conducted a second experiment in which a second computer monitor was added. Participants were shown a similar number of cues to Experiment 5.1, however, they were now presented in two contexts as denoted by the physical difference in the appearance (but not the size or resolution) of the monitors. As the distance between the cues would be greater than in Experiment 5.1, and the monitors would also clearly group the cues in a manner similar to Glautier (2002), this should increase the chance of elemental processing of cues (Rescorla & Wagner, 1972) when cues were presented on separate monitors. Consequently, this would lead to stronger blocking in the condition in which target and blocking cue were on different monitors. In addition, weaker blocking was expected when cues were on the same monitor, compared to when they were on different monitors (Glautier, 2002).

5.3   Experiment 5.2

Glautier (2002) showed that when blocking and target cue were shown on the same playing card, blocking was weaker, and when target and blocking cue were presented on separate playing card, blocking was stronger; a finding that has been interpreted in terms of elemental processing (Thorwart and Lachnit 2009). This interpretation is facilitated by the assumption that the use of two rather than a single playing card was interpreted by his participants as two distinct contexts, and the cues on the single playing card were grouped together. In the previous experiment the distance between two compound cues was approximately 15 cm (Group SR) or 23 to 24.7 cm (Group DR) and it is possible that the lack of an effect on cue competition resulted from the cues being perceived as a single unit. Despite appearing in different locations the cues were still presented on the same monitor which might have been perceived as the same context. The present experiment sought to address this issue directly by presenting

cues over two adjacent monitors rather than the single computer monitor used in Experiment 5.1, (see Livesey & Boakes, 2004, Experiment 2). The question here was whether distance between compound cues would influence cue competition effects such as blocking and overshadowing, and whether temporal estimates of cues would differ between groups.

5.3.1   Methods

Participants

Thirty participants volunteered for this experiment. Unfortunately, one participant did not understand the experiment and was excluded upon completion of the task. Mean age of participants was 28.0 (*SD*: 12.1), with a range of 18-36 and four participants being between 50 and 59. Twenty three volunteers were female, four were male, and all but three participants were native English speakers. Participants were given £4 as a thank you for completing the experiment or if they were Psychology undergraduates they could receive course credit.

Stimuli

Stimuli were visually identical to the stimuli in Experiment 5.1, however as there were fewer stimuli on one monitor in this experiment, they measured approximately 3.9 x 4.1 cm. The distance between each stimulus measured 1 cm, the far left stimulus was shown 6.3 cm from the left hand side of the monitor, and 4.6 cm from the top of the monitor, see Figure 5.11.

Procedure

The experiment paradigm was identical to Experiment 5.1; however in this experiment stimuli were presented on two monitors, not in two rows on the same monitor. Stimuli were presented on two black 19" Dell monitors. The monitors were different models with different physical appearances: the right monitor had a broader frame than the other (right monitor frame was approximately 4 cm, the left monitor frame was 1.5 cm) and the right monitor had a more curved/ streamlined appearance.

Participants were situated equidistantly between two adjacent computer monitors and cues were presented in rows of five along the top of each monitor. There were five stimulus locations along the top of the left monitor and five stimulus locations along the top of the right monitor; see Figure 5.10a and 5.10b for screenshots. In this experiment

compound cues (blocking and target or the two overshadowing cues) were presented 15 cm apart in the group in which compound cues were presented on the same monitor (Group SM). In the group in which compound cues were presented on different monitors (Group DM) the distance between the compound cues ranged from 30 to 46.2 cm, depending on the counterbalancing condition. Cue outcomes (lightning bolts) were always shown on the left monitor, as were the Likert scales for the causality judgements and temporal estimates. Participants were informed the USs and Likert scales would only be shown on the left monitor prior to starting the experiment and were instructed to look at both monitors. Participants were randomly assigned to either one of two experimental groups.
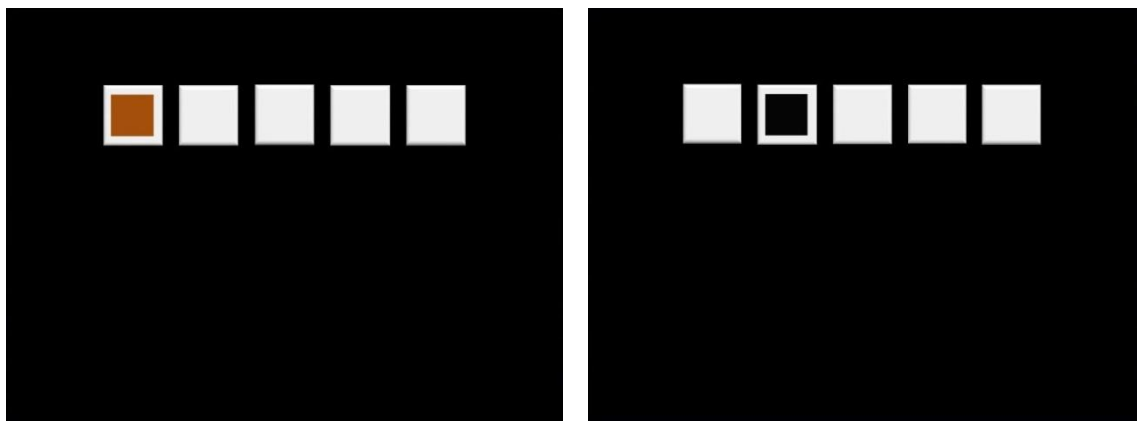
Figure 5.10a. Example of compound cue presentation for Experiment 5.2 on left and right monitor (left and right respectively).
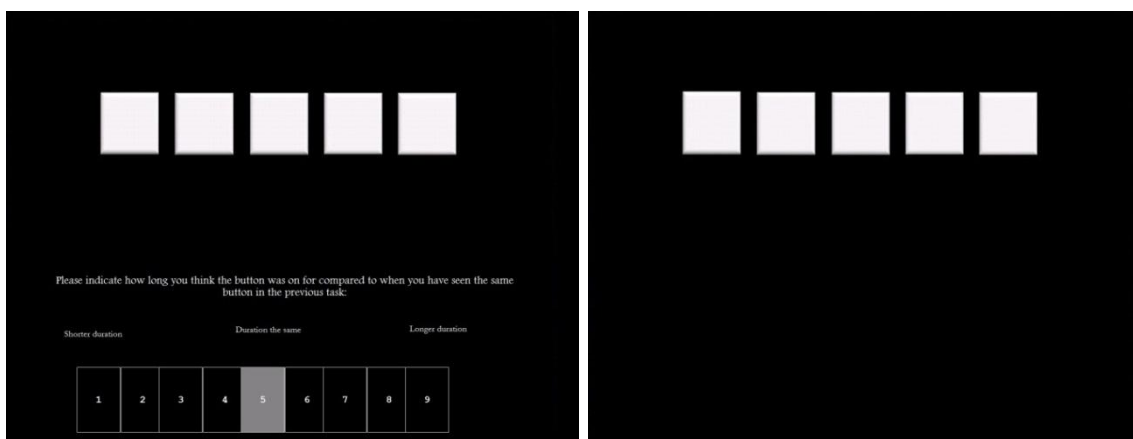
Figure 5.10b. Example of temporal estimation screens for Experiment 5.2 with score '5' highlighted on left monitor, and five buttons that are not showing any stimuli on the right monitor (left and right respectively).

All conditions were counterbalanced, and there were no differences in causality ratings or temporal estimates when comparing counterbalancing conditions. Between-

subjects ANOVAs compared Groups (SM and DM) with Groups as a factor. There was no effect of monitor on causality ratings: for overshadowing cues and positive control: $F < 1$ and for blocking scores: $F(1, 25) = 1.35$, $p = 0.26$. There was also no effect of monitor in causality ratings when comparing the counterbalancing condition in which target cue was on same monitor as US, or not: for overshadowing cues and positive control: $F < 1$ and for blocking scores: $F(1, 25) = 2.70$, $p = 0.11$.

Temporal estimates were unaffected by the location of the US; when the blocking cue was on same monitor as US, or not there was no difference in temporal estimates for the two overshadowing cues and the positive control: $F < 1$ or for blocking and target cue $F(1, 25) = 2.27$, $p = 1.44$. When the target cue was on same monitor as US, or not, there was also no differences in participants' estimates; for the overshadowing cues and the positive control: $F(1, 25) = 2.43$, $p = 0.13$ for the blocking and target cue: $F(1, 25) = 1.89$, $p = 0.18$. Therefore, the data were pooled without recourse to including monitor as a random effect.

5.3.2   Results

Overshadowing

Means and standard deviations were very similar for the two overshadowing cues: O1 M: 6.48, SD: 2.65 and O2 M: 5.86, SD: 3.32. The causality ratings of the overshadowing cues were submitted to a two Cue (O1 and O2) x two Group (SM and DM) within-subjects ANOVA with both Cue and Group as repeated measures. The analysis showed the participants' causality ratings for the two overshadowing cues (O1 and O2) did not differ (no effect of Cue: $F < 1$). Furthermore, there was no main effect of Group ($F < 1$) and no Group x Cue interaction ($F(1, 54) = 1.56$, $p = 0.22$).

Causality ratings for the mean of the two overshadowing cues and control cue were compared. The causality ratings of the overshadowing cues were submitted to a three Cue (O and C) x two Group (SM and DM) between-subjects ANOVA with both Cue and Group between- subjects factors. The analysis showed that the mean ratings for the overshadowing cues were significantly lower than that of the control cue ($F(1, 54) = 22.78$, $p < 0.001$), see Figure 5.11. There was no difference when comparing Group SM and DM ($F < 1$), and there was no Cue x Group interaction ($F < 1$). Thus, overshadowing was observed in each group and, furthermore, the distance between overshadowing cues did not influence overshadowing.
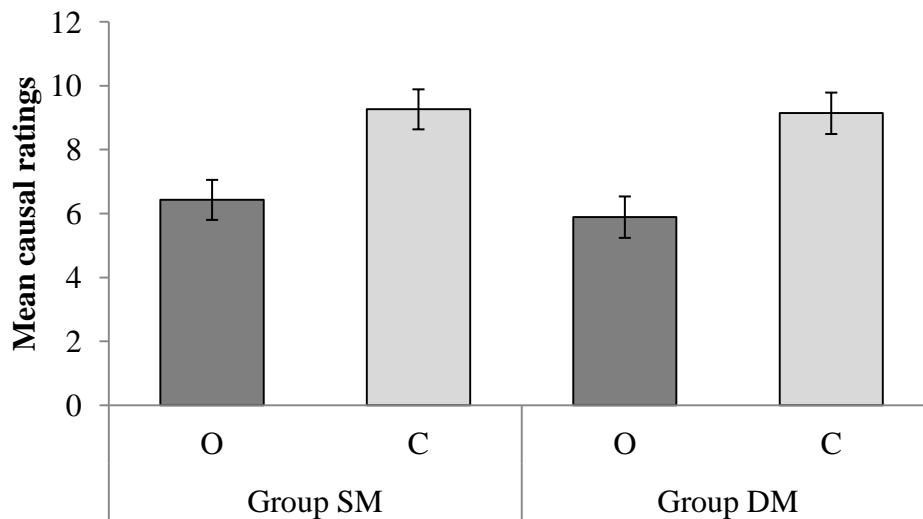
Figure 5.11. Mean causality ratings for the mean of both overshadowing cues (O) and the postive control (C) for Group SM and Group DM. Error bars show ± 1 *SEM*.

Blocking

A one sample t-test showed blocking in Group SM; $t(13) = 3.63$, $p < 0.01$, but not in Group DM; $t(14) = 1.39$, $p = 0.19$, see Figure 5.12. However, the blocking effect was skewed by the presence of an outlier; once removed from the analysis there was a significant blocking effect for Group DM $t(13) = 2.43$, $p = 0.03$. There was no difference between groups when comparing blocking scores ($t(27) = 1.16$, $p = 0.26$); therefore, distance between blocking and target cue did not influence blocking.
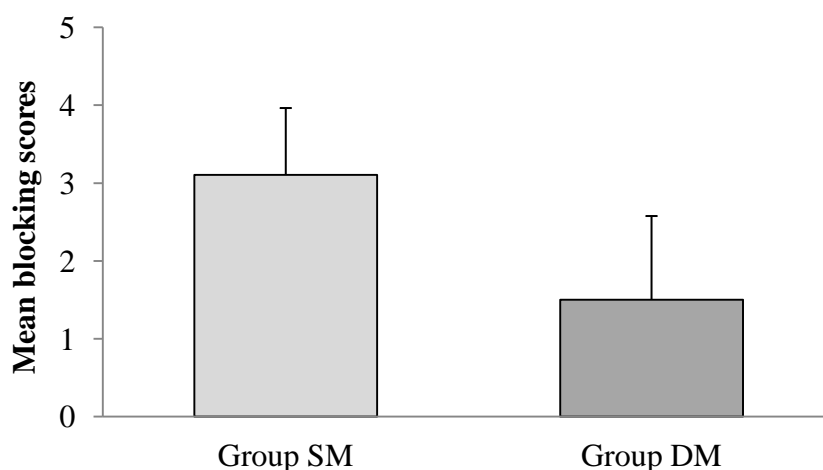
Figure 5.12. Mean blocking scores for Group SM and Group DM with outlier included. Error bars show + 1 *SEM*.

Temporal Estimation

Overshadowing and control cues

One sample t-tests showed that the mean temporal estimates for both overshadowing cues did not differ from five in Group SM (O1: $t(13) = 0.95$, $p = 0.36$ and O2: $t(13) = -0.07$, $p = 0.95$,) see Figure 5.13. For Group DM, the mean temporal estimates for the two cues also did not differ from five (O1: $t(14) = 0.09$, $p = 0.93$ and O2: $t(14) = 0.05$, $p = 0.96$).
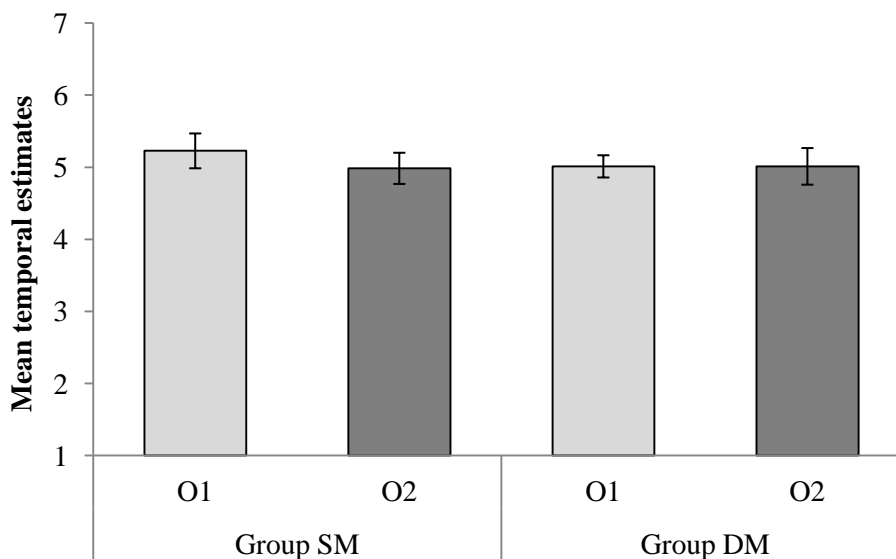
Figure 5.13. Mean temporal estimates for the two overshadowing cues (O1 and O2) for Group SM and DM. Error bars show ±1 *SEM*.

Temporal estimates for the two overshadowing cues (O1 and O2) for the target duration (1900 ms) were very similar. The estimates were submitted to a two Cue (O1 and O2) x two Group (SM and DM) within-subjects ANOVA with both Cue and Group as repeated measures. The ANOVA showed no main effect of Cue ($F(1, 27) = 3.16$, $p = 0.09$). There was also no main effect of Group ($F < 1$) and no Cue x Group interaction ($F(1, 27) = 1.09$, $p = 0.31$).

Temporal estimates for the positive control cue were very close to five in both groups for the target duration (1900 ms); Group SM had *M*: 5 (*SD*: 1.66) and Group DM had *M*: 5 (*SD*: 2.04). One sample t-tests for the temporal estimates indicated they did not differ from five for either group; Group SM $t(13) = 0$, $p = 1$ and Group DM $t(14) = 0$, $p = 1$. An independent t-test showed no difference between the two groups for the target duration estimates ($t(27) = 0$, $p = 1$).

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To compare temporal estimates of the two overshadowing cues and the control cue, the estimates were submitted to a three Cue (O1, O2 and C) x two Group (SM and DM) within-subjects ANOVA with both Cue and Group as repeated measures. There was no difference between temporal estimates for overshadowing cues (O1 and O2) and positive control cue when analysed with an ANOVA (Cue: $F < 0$), see Figure 5.14. There was no main effect of Group for temporal estimates ($F < 0$), and there was no Group x Cue interaction ($F(2, 54) = 1.71$, $p = 0.19$).
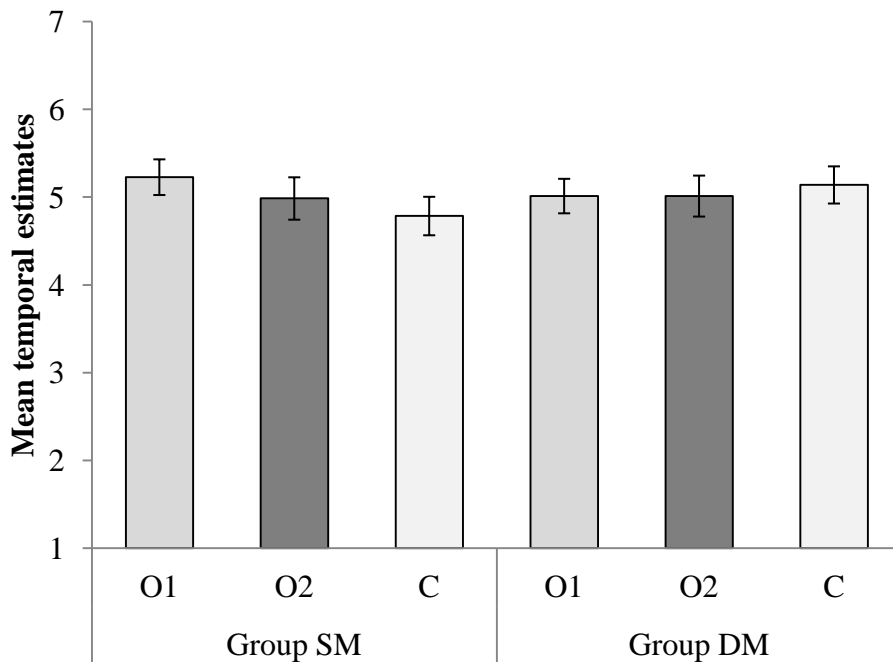
Figure 5.14. Mean temporal estimates for the two overshadowing cues (O1 and O2) and the control (C) in both groups (SM and DM). Error bars show ±1 *SEM*.

Group SM standard deviations for the two overshadowing cues (first and second) and the positive control were 0.90, 0.81 and 0.87 respectively. The standard deviation for one of the overshadowing cues in Group DM was slightly lower, $SD = 0.60$, for the other overshadowing cue was 0.98 and for the positive control was 0.77. To compare temporal estimates of the two overshadowing cues and the control cue the estimates were submitted to a three Cue (O1, O2 and C) x two Group (SM and DM) within-subjects ANOVA with both Cue and Group as repeated measures. The standard deviations for temporal estimates for the overshadowing cues and the positive control (O1, O2 and C) did not differ when analysed with an ANOVA ($F(2, 54) = 2.90$, $p = 0.06$) (see Table 5.2), though a trend could be observed. When collapsing all temporal estimates (across test durations), there was no difference between standard deviations

between the two groups ($F < 1$), and no Group x Cue interaction for standard deviations ($F(2, 54) = 1.66$, $p = 0.20$). Therefore, the distance between the overshadowing cues did not influence the temporal estimates.

Blocking & target cue

The temporal estimates for the means of the probe durations for the blocking cue were compared. The temporal estimates of the blocking cue were submitted to a five Duration (1425, 1663, 1900, 2138 and 2375 ms) x two Group (SM and DM) within-subjects ANOVA with both Duration and Group as repeated measures. Analysis showed a main effect of Duration (ANOVA: $F(4, 108) = 20.83$, $p < 0.001$, see Figure 5.15). There was no Duration x Group interaction ($F(4, 108) = 1.35$, $p = 0.26$) and there was no main effect of Group ($F(1, 27) = 1.11$, $p = 0.30$.
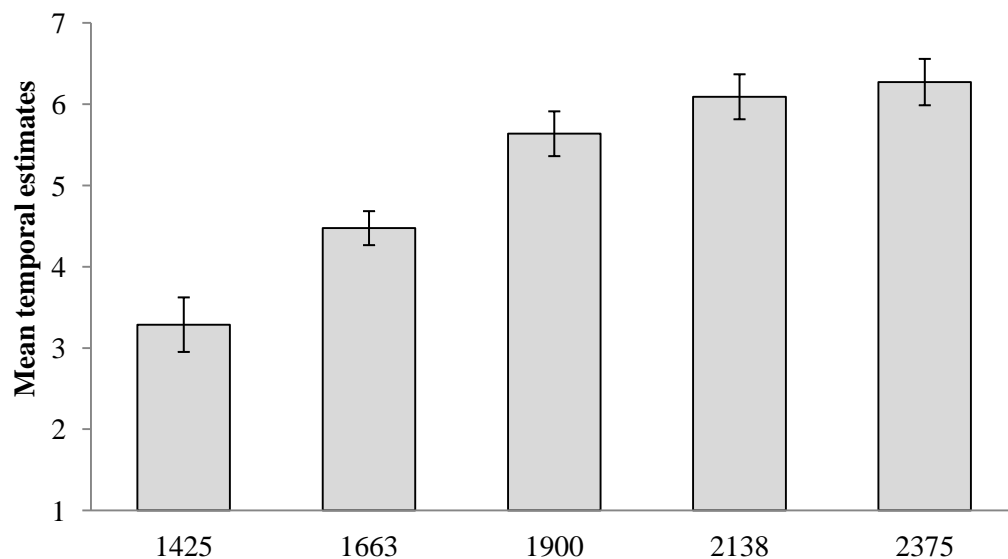
Figure 5.15. Mean temporal estimates for the five probe durations for the blocking cue. Durations were in milliseconds. Temporal estimates were on a Likert scale ranging from one (shorter) to nine (longer). Error bars show ±1 *SEM*.

Temporal estimates for the target cue were also analysed. The temporal estimates of the target cue were submitted to a five Duration (1425, 1663, 1900, 2138 and 2375 ms) x two Group (SM and DM) within-subjects ANOVA with both Duration and Group as repeated measures. For the target cue there was a difference in temporal estimates between the five probe durations when testing with an ANOVA (Greenhouse-Geisser correction: $F(2.85, 76.90) = 9.70$, $p < 0.001$). There was no Duration x Group interaction ($F(2.85, 76.90) = 2.03$, $p = 0.12$). Means were very similar for groups

(Group SM: $M = 4.99$, $SD = 1.44$ and Group DM: $M = 4.96$, $SD = 1.92$) and there was no main effect of Group ($F < 1$).

The standard deviations of temporal estimates of the blocking and target cue were submitted to a two Cue (B and T) x two Group (SR and DR) within-subjects ANOVA with both Cue and Group as repeated measures. The standard deviations for temporal estimates for the blocking and target cue did not differ ($F < 1$), and there was no Cue x Group interaction between standard deviations ($F < 1$). There was a main effect of Group ($F(1, 27) = 5.77$, $p = 0.02$, Figure 5.16), with more variation in estimates in Group DM.
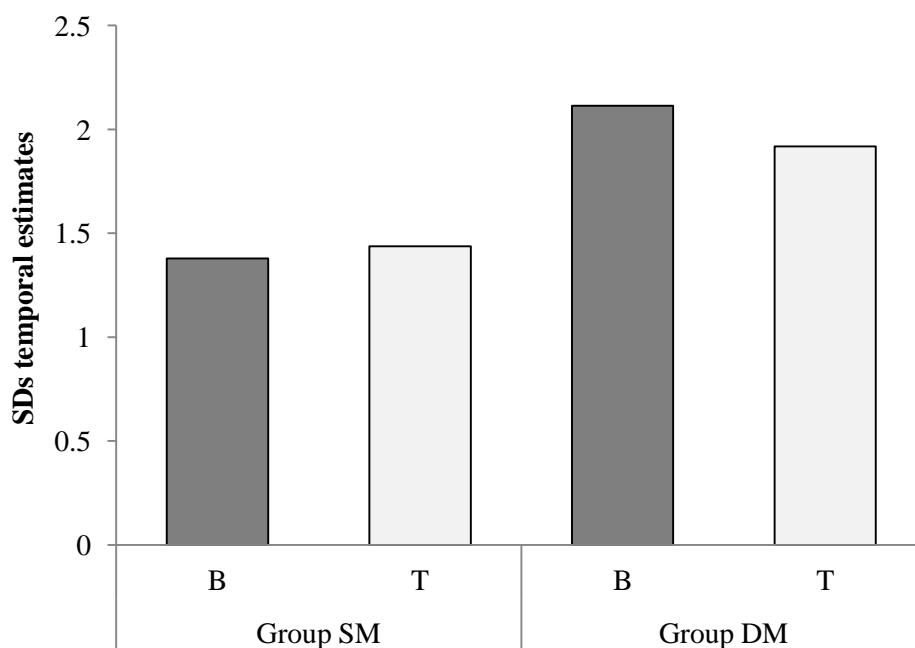
Figure 5.16. Standard deviations (SDs) of mean temporal estimates for the blocking (B) and target cue (T) in Group SM and DM.

In Group SM, participants were accurate at estimating the pre-trained target duration for the blocking cue ($t(13) = 0.56$, $p = 0.58$) but not the target cue ($t(13)$ 2.01, $p = 0.07$). For Group DM participants were accurate at assessing the duration for the target cue ($t(14) = -0.37$, $p = 0.72$) but not the blocking cue ($t(14) = 2.38$, $p = 0.03$), see Figure 5.18.

The temporal estimates of the blocking and target cue for the pre-trained target duration (1900 ms) were submitted to a two Cue (B and T) x two Group (SR and DR) within-subjects ANOVA with both Cue and Group as repeated measures. There was no difference in temporal estimates between blocking and target cue for the pre-trained

target duration, $F < 1$. Participants were accurate at estimating the blocking cue in Group SM and the target cue in Group DM, however they overestimated the duration for the target cue in the Group SM, and the blocking cue duration in Group DM. This was shown in the Cue x Group interaction ($F(1, 27) = 11.89$, $p < 0.01$, Figure 5.17).

A simple main effects analysis showed a difference between blocking and target cue estimates when they were on different monitor ($F(1, 54) = 5.15$, $p = 0.03$), yet no difference between blocking and target cue estimates when cues were on the same monitor ($F(1, 54) = 1.85$, $p = 0.18$). There was no main effect of Group ($F < 1$).
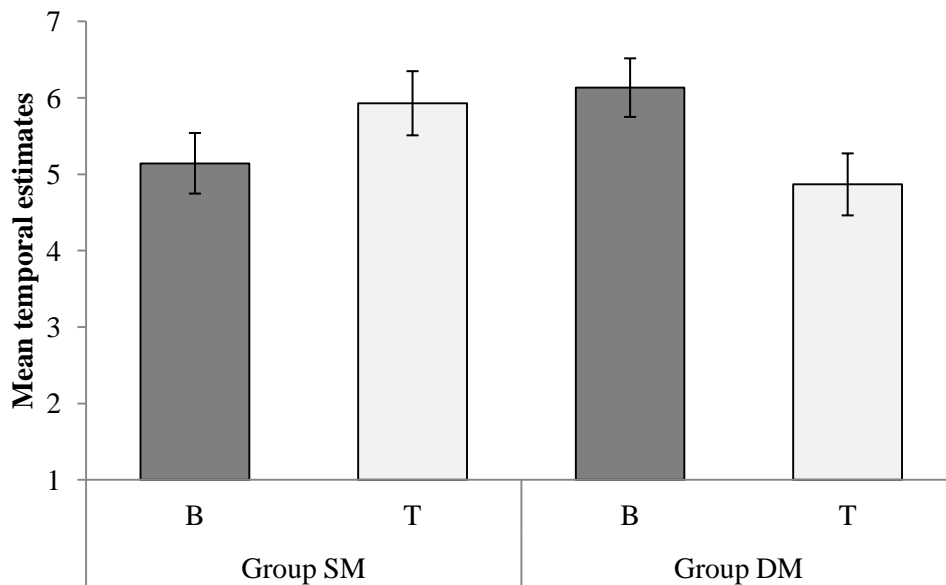
Figure 5.17: Mean temporal estimates for the target duration for blocking cue (B) and target cue (T) for Group SM and DM. Error bars show ±1 *SEM*.

Overall, temporal estimates of the blocking and target cue showed more variation in Group DM than for Group SM. Participants showed accurate estimates for the target duration for the blocking cue in Group SM; however they were inaccurate at estimating the duration in Group DM. The reverse was the case for the target cue (inaccurate in Group SM, accurate in Group DM). These findings indicate that the distance between target and blocking cue influenced temporal estimates during blocking.

5.3.3 Discussion

The results of the present experiment showed there were no differences between groups in either overshadowing and blocking scores. Therefore, even though the distance between the blocking and target or the two overshadowing controls was 200

and 308% greater in Group DM compared to Group SM, this did not influence cue competition. Consequently, these results contradict the prediction that cue distance would lead to weaker blocking and overshadowing effects. No difference was observed in blocking or overshadowing between the groups in which cues were presented on the same unit (and closer together) compared to the group in which they were on separate units (and further apart). This differs from previous experiments that studied influence of distance in blocking and overshadowing (Glautier, 2002; Livesey & Boakes, 2004; Martin & Levey, 1991). Nevertheless, these findings are consistent with those presented in Experiment 5.1.

Participants showed greater variation in their temporal estimates in Group DM than Group SM; there was a difference between standard deviations for the target and blocking cue, and though no significant difference between standard deviations of the two overshadowing cues and the positive control was found, this did approach significance. In Experiment 5.1 there was also a difference in standard deviations between groups.

The temporal estimates for the pre-trained target duration for the blocking and target cue were also similar to Experiment 5.1. In Experiment 5.2 participants were not accurate at estimating durations for target cue in Group SM and blocking cue in Group DM, and there was an interaction between cue and group for the blocking and target cue when looking at estimates for the actual duration. From these results we can conclude that participants did not generalize estimates between blocking and target cue.

5.4   General Discussion

The present series of studies have shown that cue competition was not affected by physical distance between the cues, either as a function of being displayed on the same or a different monitor. This is in contrast to a number of studies (e.g. Glautier, 2002; Livesey & Boakes, 2004; Martin & Levey, 1991) where a weaker blocking effect was shown as a consequence of cue proximity. In the previous studies (e.g. Glautier, 2002; Livesey & Boakes, 2004; Martin & Levey, 1991) participants were pre-trained with a specific cue setup to encourage configural processing. Cues were processed elementally in both groups in Experiment 5.1 and 5.2. As a result, cues were processed individually and each element (of a cue) was linked to an outcome and there was no generalization between outcomes of compounds cues (as would be the case if they were

processed configurally). Therefore, spatial distance did not affect blocking and overshadowing.

The findings of Experiment 5.1 and 5.2 were in line with Thorwart and Lachnit (2009) who did not find a difference in cue competition between conditions in which spatial arrangement of cues varied. They found no difference in responses between groups in which cues were clearly grouped or not. Thorwart and Lachnit (2009) suggested there was no difference between groups because they did not have a causal learning paradigm. They argued that other studies in which there was a 'grouping' effect (and weaker blocking as a consequence) used a causal learning paradigm. Yet, the paradigm in Experiment 5.1 and 5.2 was also causal, yet no weaker blocking was observed.

As there was no difference between blocking and overshadowing between groups in the above experiments, the results indicate that participants did not generalize the causality ratings between cues when they were closer together, thus not providing support for generalization when cues are more similar as was proposed in the configural model (Pearce, 1987, 1994). More specifically, blocking was not weaker in one group, which suggests that the cues were processed as individual units rather than paired units. This is because, if they had been processed configurally, cues that were closer together would have been processed as one unit, and the same causality rating would have been given to both cues. Therefore, the results supported elemental models that can explain blocking and overshadowing (e.g. Mackintosh, 1975b; Pearce & Hall, 1980; Rescorla & Wagner, 1972).

Participants were not able to accurately estimate durations in the test phase; there was a difference between estimates for the target duration in both experiments for the blocking and target cue. Temporal estimates for the overshadowing and control cues were not accurate in Experiment 5.1 as the mean temporal estimates differed from the target score (five) for the overshadowing cues in the Group DR. The mean estimate for the control cue also differed from the target score in Group SR. In Experiment 5.1 and 5.2 participants showed a greater variation (standard deviation) in mean estimates when comparing groups for each experiment separately. In Experiment 5.1 and 5.2 temporal estimates for the blocking cue and target cue differed for the pre-trained target duration. Therefore, there was an effect of distance between cues, in particular, for the blocking and target cue.

The effect of distance between cues on temporal estimates could be due to the kappa effect (Cohen et al., 1953). For example, the temporal estimates for the

overshadowing controls were higher in the group in which cues were further apart, than the group in which cues were closer together. Thus, confirming the prediction that spatial location would influence temporal estimates.

The results in the above experiments are not supported by a timing model such as the SET (Gibbon, 1977), as this model predicts that timing does not vary between stimuli of the same modality, i.e. in Experiment 5.1 and 5.2 the cues were all visual, so in this case, temporal estimates should have been similar in all groups and for all cues; which was not the case in Experiment 5.1. Moreover, the standard deviations varied between groups for Experiment 5.1 and 5.2, which is not in line with the SET assumptions. Therefore, the results in Experiment 5.1 and 5.2 did not support the SET model.

However, if durations are encoded together with associations, associative models (for example: Rescorla, 1973; Wagner, 2003) could make predictions about temporal estimates. The models predict a decrement in responding for the target cue compared to the blocking cue. The decrement in responding to the target cue could have been manifested as an inaccuracy of the target cue temporal estimate. As a result, the target cue is blocked and the temporal estimates are more varied. Also, there should be no difference between groups in temporal estimates, yet this was not the case as there was a main effect of group for blocking and target cue in both experiments. Pearce's (configural) generalization theory (Pearce, 1987) cannot explain the results either; according to his theory if two cues are close together they are more similar and so responses to the cues are generalized. Therefore, it could be assumed that the temporal estimates for the two cues are similar, yet this was not the case.

To conclude, distance between cues did not influence blocking and overshadowing in this paradigm, yet it did influence temporal estimates. The blocking and overshadowing findings are in line with previous research (Thorwart & Lachnit, 2009) and can be explained by associative learning models such as the RW model (Rescorla & Wagner, 1972). However, neither timing (such as SET; Gibbon, 1977) nor associative learning models (e.g. RW model) can explain the temporal estimation results

Chapter 6. General Discussion

Aims addressed

The aims of this study were to test an experimental setup which would successfully test learning and timing, and to investigate the role of cue competition on learning and timing by seeing whether cue competition effects would be correlated with timing deficits. I also investigated whether cue duration affected learning and timing and tested whether cue location, colour or shape affected learning and timing. Chapter 2 set out to test the experimental setup and whether it could successfully test blocking and temporal estimates and Chapter 3 set out to test differences between groups with varying visual cue properties. In addition, Chapter 4 tested whether blocking and overshadowing would be weaker or stronger when relative cue duration differed for compound cues and Chapter 5 looked at whether relative cue location of compound cue impacted cue competition.

Experimental findings

In Chapter 2 several experiments set out to test slightly different experimental setups. The setups were similar to previous human learning experiments which havepreviously shown blocking (Boddez et al., 2011; De Houwer & Beckers, 2003; De Houwer et al., 2002). The experiments in Chapter 2 showed blocking was possible with the experimental setup and also enabled participants to give temporal estimates of cues. The analyses showed that the duration test was a good way of testing temporal estimates and participants were accurate at assessing the durations of the cues. The experiments were therefore suitable for testing influence of cues, location and cue duration on blocking.

Experiments in Chapter 3 looked at influence of stimulus properties as previous research has shown that various stimulus properties, such as shape, colour, size and location, influence cue competition (Alexander, Wilson, & Wilson, 2009; Prados, 2011). In the first two Experiments (3.1 and 3.2), blocking occurred in groups in which cues had fixed locations and blocking was attenuated in groups in which cues had variable locations during training and testing. However, this was not the case for Experiment 3.3 in which only one group showed attenuated blocking, namely the group in which stimuli were the same colour, had a different shape and did not have a fixed location (SC-DS-NFL). In Experiment 3.3 there was an effect of number of elements on blocking. In all three experiments, temporal estimates were influenced by colour and

number of elements. It could be concluded from these experiments that location is an important cue property which aides participants in causality rating (Dibbets et al., 2000) and that cue colour and number of elements influenced temporal estimates.

Stimulus duration has been found to be important in conditioning and associative learning (Barnet, Grahame, & Miller, 1993; Savastano & Miller, 1998). Thus, in experiments in Chapter 4 different stimulus durations were tested; the blocking stimulus was either longer or shorter than target stimulus. In both experiments there was no difference between the groups in which blocking cue was longer or shorter. The temporal estimates did not differ between cues for Experiment 4.1 in which cue duration did not differ as much between cues (25 % difference). However, in Experiment 4.2 temporal estimates and coefficients of variance did differ between groups. Therefore, the experiments showed there was a level of consistency between human and animal causality rating tasks and results.

Spatial learning experiments have demonstrated cue competition effects, suggesting that these types of tasks are amenable to associative theorising (for review see Chamizo, 2003). Therefore, Experiment 5.1 and 5.2 tested whether cue competition and duration estimates differed when cues were closer together or further apart than in a control group. Data from Experiment 5.1 and 5.2 showed that magnitude of the cue competition effect was not influenced by proximity of the cues to each other. The temporal estimates results showed there was an effect of distance between cues, in particular, for the blocking and target cue.

From the experiments above we can conclude that cue properties did influence learning. Namely, participants were slightly influenced by the colour of the cues (temporal estimates were influenced in Experiment 3.1). Experiment 3.2 showed that cue location influenced learning as temporal estimates for the blocking cue varied. The number of cue properties also influenced learning which was illustrated by results in Experiment 3.3 which showed that the number of cue properties participants had to distinguish cues by influenced temporal estimates. Experiment 4.1 showed that cue duration influenced learning as variance in temporal estimates differed between cues with dissimilar durations. Lastly, it was found that cue location also influenced learning. Experiment 5.1 and 5.2 showed that distance between cues did influence cue duration estimates for the blocking and target cue estimates in particular.

As stated above, in most experimental setups cue properties (i.e., colour, location and duration) mostly did not influence causality ratings of cues, but temporal estimates were influenced; i.e. blocking and overshadowing were usually observed,

whilst timing was less accurate depending on cue properties. Perhaps the cue properties influenced the amount of attention spent on stimuli, and this changed duration perception (Meck & Church, 1983; Zakay & Block, 1997). For example, Hogarth, Dickinson, Austin, Brown, and Duka (2008) found that cues with different certainty could still predict the outcome equally well, but participants paid more attention on the less certain cue. Thus, Hogarth et al. (2008) found that predictions of cue outcomes did not change, but attention spent on cues did change. Even though cue competition strength remained the same in experiments in this thesis, this did not rule out that attention levels had changed, which can influence timing (e.g. Brown, 1997; Zakay & Block, 2004).

Associative learning models

The results presented in this thesis were able to shed some light on current cue competition models. The Rescorla Wagner model (1972) predicts that a stimulus and an outcome acquire associative strength across trials. Experiment 2.1 supported this as there was a clear difference in causality ratings between trials. Another popular model is the Mackintosh model (1975) which predicted that surprising CSs would receive greater associative strength than unsurprising CSs. The experiments in this thesis do not support this theory, because in experiments in Chapter 3 when the cues had different locations (and so it was surprising where the cue was), cues received less associative strength as blocking was attenuated. In contrast, this experiment showed support for the Pearce Hall (1980) model, which predicted that contrary to Mackintosh, stimuli that were novel would receive more attention. This is in line with the results of the experiments in Chapter 3 showing blocking, even when cues did not have a set location (i.e. they had a novel location). Lastly, the experiments in this thesis did agree with the predictions made by the SOP model (Wagner, 1981) as this model proposed that cues are represented by nodes and can be in varying states of 'activity'.

Dr José Prados (University of Leicester) suggested a different model can explain the results in this thesis, namely the comparator hypothesis (Stout & Miller, 2007). According to the comparator hypothesis learning is not a result of competition but learning results from a change in the likelihood or magnitude of reinforcement relative to that in the cue's absence (Stout & Miller, 2007). The comparator hypothesis posits that the response to a target cue depends on the associative strength between the outcome and other cues, in this case known as comparators that have previously been paired with the target cue (Castro & Wasserman, 2007). It predicts that during

compound conditioning both the blocking and target cue acquire full predictive value as there is no cue competition. However, at time of test, the actual response by the participant would be modulated by a comparator device which takes into account the strength of association between the target cue and outcome, the association between blocking and target cue, and the strength of association between blocking cue and outcome. When the association between blocking cue (or other comparators) with outcome is higher than blocking cue with the target cue, blocking is observed (Stout & Miller, 2007).

Although the comparator hypothesis is not as well validated as the models discussed in the previous chapters, it may explain some of the results described in previous chapters where blocking was strong, yet duration estimates for the target cue were inaccurate. The comparator hypothesis (Stout & Miller, 2007) would predict that during compound conditioning the target cue receives full associative strength and timing would be accurate. However, at testing when the associative strength between target cue and outcome is weaker compared to blocking cue and outcome (as this cue is associated with a higher outcome), timing would be less accurate because there is less processing of the target cue. Thus, the comparator hypothesis (Stout & Miller, 2007) can explain some of the results.

Timing models

The temporal estimates in the experiments described in the previous chapters mostly varied between groups for every experiment. This did not agree with timing models discussed in the introduction such as the SET model (Gibbon, 1977, 1991; 1981) as the SET model predicts that temporal estimates are identical for cues with the same modalities. As the cues in the experiments in this thesis were all visual, they should have had similar means, which was not the case. We also observed a difference in coefficients of variance in Chapter 5 between cues with different durations, whilst the coefficient of variance should not differ between cues with different durations. Therefore, we cannot provide support for the SET model.

Hybrid models

Results from the experiments described in the previous chapters showed no evidence that timing played a role in conditioning; cue duration did not affect learning and timing, and cue competition effects did not seem correlated with timing deficits. When durations of cues were changed (Chapter 4), there was no attenuation of blocking

or overshadowing, as has been observed in some previous studies (Gaioni, 1982; Jennings et al., 2007; McMillan & Roberts, 2010). Therefore, the experiments did not provide any evidence that association and timing are encoded together (e.g. Balsam & Gallistel, 2009; Honig, 1981; Savastano & Miller, 1998). It could be that animals and humans have different learning processes (Arcediano & Matute, 1997; Le Pelley, Oakeshott, & McLaren, 2005; Mitchell et al., 2009), and that this would explain why the results observed in the previously described experiments do not agree with other findings (Gaioni, 1982; Jennings et al., 2007; McMillan & Roberts, 2010).

As timing and associative learning did not seem to be encoded together, both phenomena do not need to be modelled within a single model. This is contrary to what was suggested by for example Kirkpatrick and Church (1998) and Savastano and Miller (1998). Kirkpatrick and Church (1998) hypothesised that to be able to predict timing and associative learning accurately, hybrid models needed to be developed which could predict both timing and associative learning in one model such as the Rate Expectancy Theory (RET, Gallistel & Gibbon, 2000).

Future research

Future similar experiments should be improved as the experiments did have limitations. For example, cue properties could have been better randomised. In experiments where cue location was not fixed, and cues were shown at random locations, cue colour did not vary for cues. The cues were either all the same colour, or all a different colour. However, this colour did not change throughout the experiment. To make it harder for participants to remember cues by colour (as colour is a very salient property), every cue could have been a different colour every different trial, instead of all the same colour in all trials. This would have been more comparable to showing cues in different locations throughout trials.

Further research on influence of cue properties on cue competition and timing could test influence of increased cue saliency of the blocking or target cue, as this may influence cue competition (Mackintosh, 1975b). Perhaps instead of colours, pictures of objects and food could be used which vary in salience. For example, one cue could be a banana and another cue could be a flower pot. The banana is higher in salience as this is a food item which has biological significance (Denniston et al., 1996). In this case, cues with higher saliency would be able to cause greater overshadowing for example (Mackintosh, 1976), and because they are more salient timing could be more accurate in

those cues because participants are paying more attention to those (predicted in the SET model; Meck & Church, 1983; Zakay & Block, 1997).

To be able to test assumptions of associative learning and timing models in more detail, attention to cues could be tested and analysed by conducting experiments whilst eye-tracking participants. There are a number of researchers who agree that human attention experiments should include eye tracking as stimulus rating is not a reliable measure of attention (Kollmorgen, Nortmann, Schroder, & Konig, 2010). However, associative learning research predicts whether participants are paying attention to cues by looking at prediction scores. In the experiment described in previous chapter, causality of cues was used as measure of learning. In future, the experiments could be run whilst performing eye tracking, thereby gaze latency and frequency for specific cues would be able to be analysed. This would enable more analyses; for example, whether lower attention (lower gaze latency) corresponds with lower accuracy of duration estimates when blocking and overshadowing are still found.

General conclusion

The results suggest that timing is not encoded as part of the association. Most associative learning and hybrid models were able to accurately predict cue competition, except for in cases where information about cue properties was not clear. However, neither timing models, nor hybrid, nor associative learning models were able to predict temporal estimates. Therefore, new models should include influence of cue properties, or saliency of properties, as these might influence temporal estimates.

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Appendix

Slide: Hello

Welcome.

During the tutorial please read the information on the screen and then press <spacebar> to continue to the next screen.

The experiment consists of 3 parts.

In the first part you will just have to do a colour test, in the 2nd you will have to learn and give predictions and in part 3 you will have to take a test (about duration).

Don't worry, after every part of the experiment you can always take a break and feel free to ask questions at any point.

Press <spacebar> to continue.

Slide: Intro1a

You will now take a short test to see if you can discriminate between white and a colour.

Please press <spacebar> to read the tutorial and do the test.

Slide: Start1

During the experiment you will see a picture of buttons when they are on and off.

When the button is switched off it will be white and when it is switched on it will be coloured.

You will now do a quick test to see if you can see the difference between buttons when they are on and when they are switched off.

You will see 10 pictures in different colours.

Every picture will appear by itself on the screen.

Please type in the colour you think it is using the keyboard.

What you type will appear in the top left corner.

To submit your answer you have to press <shift>.

Once you have pressed <shift> the screen will go black and a different picture will appear until you have seen 10 pictures.

Press <spacebar> to start the task.

Slide: Intro2a

In this experiment you will see a talented magician at work.

He has built a new machine for his show; a lightning machine with which he can make lightning bolts appear.

The lightning machine is a big machine with 8 different buttons.

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The buttons all have a distinct shape. From left to right these are: parallelogram, hexagon, triangle, pentagon, circle, trapezoid, square and a cross.

If the magician presses one or more of the buttons, the button he has pressed lights up, each in its own colour.

By pressing the correct buttons, the magician can make lightning bolts appear.

The magician has also noticed that the duration for which the buttons are on for influences the appearance of the lightning.

Please press <spacebar> to read the rest of the instructions.

Slide: Intro2b

Your job is to find out exactly how the lightning machine works.

On the computer screen your will first see the lightning machine.

Then, only one or two of the buttons will be pressed.

By looking at which button(s) are pressed, you will need to figure out what will happen.

There are three possibilities:

1) No lightning bolts will appear.

2) A single lightning bolt will appear.

3) Two lightning bolts will appear.

You will enter your prediction on an evaluation scale that will appear on the bottom half of the screen.

This scale will range from 0 to 10, in which 0 is 'I definitely don't expect a lightning bolt', 5 will indicate 'I don't know' and 10 will indicate 'I am certain there will be a lightning bolt'.

When you input your answer on the evaluation scale the number of lightning bolts you expect to occur (1 or 2) will make no difference; occurrence of lightning can refer to 1 or 2 lightning bolts appearing.

Please press <spacebar> to read the rest of the instructions.

Slide: Intro2c

You can use the mouse to make your prediction on the evaluation scale by clicking within the correct box.

Following this you will see which answer you have chosen because that option will be briefly highlighted in grey.

You will then see what the lightning machine does (no lightning, single bolt or two bolts) and you will be able to assess whether your prediction was correct.

After this, you may see different buttons on the lightning machine being pressed and you will have to make a prediction again.

Don't worry, at first your predictions will be guesses. However, you will learn the connections between the buttons that are pressed and the lightning that does or does not occur afterwards.

Please press <spacebar> to read the rest of the instructions.

Slide: Intro2d:

Before you start please note:

As was mentioned previously, pressing the buttons on the machine may result in (1) no lightning bolt, (2) a single lightning bolt or (3) two lightning bolts.

You will see two lightning bolts when the magician presses two buttons that both separately cause a lightning bolt.

For example, when the circular button is pressed and would lead to a lightning bolt and the square shaped button is pressed and would also lead to a lightning bolt, this will cause two lightning bolts to appear.

You will also need to pay attention to the durations at which the buttons are on for because this is important.

After this next task the magician will ask you to complete an additional task to see if you have learnt the duration.

Please press <spacebar> to read the rest of the instructions.

Slide: Intro2e

Before you start please also keep in mind:

Sometimes the curtain will be closed, and you will not be able to see what the machine has done.

At this point in time you won't see what's happening behind the curtain. This means that you won't be able to check if no lightning bolts appear, one lightning bolt appears or two lightning bolts appear.

Don't worry about this. When the curtain is closed, you should just enter your expectation on the evaluation scale depending on what you have seen and learned about previously. It does not influence anything.

Also, please do not click the mouse before the evaluation scale has appeared and do not click outside the boxes.

Please press <spacebar> to start the experiment.

Slide: Intro3

The magician needs to run an additional test of his machine. If he presses the button for too short or too long then the lightning bolt will not appear at the correct time and the

act will be ruined. Your task is to compare the duration that each button is lit during this test with those seen during the previous show.

As before, in the first slide you will see all 8 buttons switched off or white.

The magician will then press one of the buttons and it will become coloured for a certain length of time. It will then switch off and become white again.

This time you will not see if any lightning appears or not, the curtains will stay closed.

 You will need to determine whether the duration you have just seen is the same as the duration of that button in the previous show.

Please press <spacebar> to continue.

Slide: Intro3

After the buttons have switched on and off again, you will see a screen with two questions and you will have to answer both of them.

Question 1 will ask you if you think the duration you just saw (the duration that the button was on/coloured) was the same as for this button as seen in the previous part of the experiment.

This will be a yes/no answer.

Question 2 will ask you how certain you are of your answer. You can type in any number from 0 to 100; 0 being the lowest score you can give for example if you are very uncertain about you answer and you can type in 100 when you are absolutely sure of your answer.

Your answers will appear in the top left corner whilst you type and if you make a mistake you can use backspace.

Please give both answers separated by a <space>.

You can press <SHIFT> to input your answer.

After that, the screen will go black for a few moments and you will see 8 buttons and one will become coloured again.

This part of the experiment will end when you have seen and judged every button 3 times.

Press <spacebar> to start the experiment.

Slide: Q3

1) Was that duration the same as the duration in the previous part of the experiment?

Please type in a yes or no answer for question 1.

2)How sure are you of your answer?

   Please type in a score from 0 to 100 for question 2;

0 being the lowest score you can give when you are not at all certain of your answer and 100 when you are absolutely sure of your answer.

Please separate the answers with a <space>.