A Cognitive Exploration of the Development and Control of Attentional Bias

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Thesis Abstract

Human behaviour is shaped by what we attend to in the visual world. This visual attention can be internally guided by behavioural goals, which forms the basis of attentional bias. Attentional bias is a phenomenon where certain items capture and hold visual attention over others, and is a driving force of many behaviours (e.g. seeking food when hungry). However despite the obvious links between visual cognition and attentional bias, much of the research relating to attentional bias is actually based in psychopathology, examining drivers for addictive substances. Consequently, little is known of the shared, cognitive aspects of attentional bias. This thesis addresses this by firstly examining the cognitive mechanisms that underlie attentional biases in a normative sample. It was found to be possible to induce an attentional bias towards an arbitrary stimulus. This induced bias is both highly persistent and robust. The cognitive basis of this induced bias is believed to be altered attentional control settings, which can form in the absence of emotion or motivation. Since attentional bias most often manifests in abnormal populations, the effects of these altered attentional control settings was then examined in a controlled, sub-clinical population of heavy social drinkers. This offered a means to examine the role of existing attentional biases yet free from confounds of using a clinical sample. No difference in the establishment of an attentional bias between light and heavy drinkers was found, however heavy social drinkers were less distracted by irrelevant, bias-related information suggesting previous experience controlling for attentional biases aids the cognitive control of bias-related distractions albeit with limited capacity. Finally, a neural substrate of attentional bias was probed via neurostimulation, finding a causal role of the left dorsolateral prefrontal cortex in the establishment of attentional control settings, and the control we have over distractions resulting from these settings.

A Cognitive Exploration of the Development and Control of Attentional Bias

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Declarations

This thesis is based on research carried out at the Department of Psychology, Durham University. No part of this thesis has been previously submitted for a degree at this or any other university. The work carried out and the composition of this thesis has been conducted by me.

Statement of Copyright

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Dedication

This thesis is dedicated to the memory of Sue Knight. My inspiration when times were tough and the most wonderful friend and mother a person could have. I hope I can keep making you proud.

Chapter 1
General Introduction

Overview

An attentional bias occurs when items in the environment capture and hold attention more than they should ordinarily do so. Previously, it has only been exclusively examined from an abnormal perspective, with its development and behavioural effects studied in a wide range of psychopathologies ranging from emotional disorders to addictions. Consistent findings of the same behavioural effects of attentional bias across abnormal populations suggest there is a cognitive mechanism of attentional bias common to all populations exhibiting the behaviour. However, despite the obvious links between the study of visual attention and the phenomenon of attentional bias, attentional bias has never been studied from a purely cognitive perspective. Consequently, this cognitive mechanism remains unknown. This chapter reviews findings from the cognitive literature on visual attention, abnormal literature on psychopathological attentional biases and neurobiological literature on the deployment and control of visual attention to outline the argument of this common cognitive mechanism of attentional bias. Current methodologies used to study attentional bias are reviewed, before outlining how this thesis will approach the various questions raised to investigate the cognitive mechanisms underlying the development, control and neurobiology of attentional bias.

1.1 Introduction

An essential requirement of everyday life is the ability to navigate the world around us. This entails a constant need to visually explore our environment. However, it is widely acknowledged that there is too much sensory information in the world to be able to process everything in the environment at a given time (Broadbent, 1958; Treisman, 1969). Thus, there must be some form of selective processing that filters out the irrelevant information from the relevant; otherwise known as attention. There are two main factors that are involved in determining how attentional resources are allocated during our visual explorations of the world. These are external factors which stem from the physical properties of items (Itti & Koch, 2000), and internal factors via our current behavioural goals (Hopfinger, Buonocore, & Mangun, 2000). These mechanisms of deploying visual attention are evolutionarily advantageous. Externally-driven orienting can help ensure survival (the sudden movement of a predator will capture attention, increasing the likelihood that a fight or flight response can be activated in time). Internally-driven orienting on the other hand can help to satisfy objectives also necessary for survival, such as finding food or water. As aptly summed up by Berger, Henik and Rafal (2005): "the orienting of attention reflects a competition between inner goals and external demands" (p. 207).

An extension of internally-driven orienting of attention is the phenomenon of attentional bias. An attentional bias occurs when certain items capture and hold attention more than they should ordinarily do so (Field & Cox, 2008) based on their physical properties. It is the mechanism used by the autonomic nervous system to achieve and/or satisfy both regulatory (essential for survival) and non-regulatory (non-essential for survival) behavioural goals – be these goals conscious or not. Attentional biases are most commonly observed in various clinical populations when attending to particular items is detrimental to health (Bearre, Sturt, Bruce, & Jones, 2007; Field & Eastwood, 2005; Sharma, Albery, & Cook, 2001). Whilst this abnormal literature has provided certain insights into attentional biases in maladaptive settings, there is a lack of understanding of the purely cognitive aspects of attentional biases, including how attentional biases form and the boundary

conditions that determine their formation and sustainability across both abnormal and normative populations. This chapter shall present evidence from the cognitive literature on the orienting of attention, the abnormal literature on maladaptive biases and the neurological literature on visual attention that suggests a shared, cognitive foundation of attentional bias. This shall be followed by a review of the current methodologies used to study attentional bias, before outlining how this thesis will overcome present issues.

1.2 Physical Saliency vs Behavioural Goals

Physical saliency relates to how much one item stands out from its surroundings. Typically, the most salient item in a scene is attended to over and above other items. For example, a sensory cue such as a flashing light or the sudden onset of a stimulus in a static array will cause an automatic and reflexive allocation of attentional resources towards the cue, resulting in it effectively forcing its way into visual awareness (Koch & Ullman, 1985).

This role of bottom-up information on initial attentional capture has been extensively explored by Theeuwes and colleagues (Theeuwes, 1991, 1992, 1994, 2004; Theeuwes & Godijn, 2002; Theeuwes, Kramer, & Kingstone, 2004). In these experiments, a unique task-irrelevant singleton presented amongst task-relevant items was found to reflexively capture attention. It was argued that the uniqueness of the irrelevant singleton caused it to be processed, resulting in the initial allocation of attentional resources towards it. This capture of attention occurred against the top-down goal to detect an alternative item. It was concluded that the initial allocation of attention is determined solely by the physical properties of objects. Only after the most salient item has been attended to can top-down factors play a role and items relating to behavioural goals attended. A more recent evolvement of this theory does re-evaluate the role of top-down involvement arguing that the initial bottom-up exploration of a scene occurs within a pre-defined 'attentional window', whose size does depend on behavioural goals, and is thus under top-down control (Belopolsky & Theeuwes, 2010; Belopolsky, Zwaan, Theeuwes, & Kramer, 2007). Nevertheless, the primary argument is maintained in that within this window, top-down influences can only occur after an initial bottom-up exploration

of a scene. While this model appears logically sound, other theorists argue that only objects that are potentially relevant to our goals can initially capture attention. An example of this would be attentional biases, as these are the orientation of attention towards items that consciously or unconsciously satisfy behavioural goals. Furthermore, many experiments not examining attentional bias also demonstrate that the most salient object in a visual scene does not necessarily capture visual attention (Bacon & Egeth, 1994; Folk & Remington, 1998; Folk, Remington, & Johnston, 1992; Leber & Egeth, 2006b; Soto, Humphreys, & Heinke, 2006). It therefore follows that other factors must sometimes influence the initial allocation of visual attention.

One example is the priming effect, wherein a target's location on a previous trial can have an effect on the speed of detection in subsequent trials (Kristjansson & Driver, 2008). Since attentional bias triggers an involuntary urge to attend to a particular item (Field & Cox, 2008), it could be argued that attentional bias occurs when bias-related items are somehow continuously primed, resulting in these items frequently capturing visual attention. Evidence is observed in studies of maladaptive biases relating to addiction where attention is involuntarily captured by bias-related items, whether related to task demands or not (Jones, Bruce, Livingstone, & Reed, 2006). Here, the reflexive capture of attention by bias-related items suppresses voluntary aims to attend to task-relevant information (Hester & Garavan, 2009; Nikolaou, Field, Critchley, & Duka, 2013). Furthermore, this is internally prompted as bias-related items are not necessarily the most physically salient. However, it should be noted that categorising priming as a top-down effect is controversial. Theeuwes (2010b) argues that since intertrial priming affects very early processing observed via latency and amplitude alterations of the P1 Event Related Potential (ERP) component at around 80-130ms, it cannot be under top-down control and should be considered as a bottom-up process. However, this argument assumes that early processing and bottom-up processing are one in the same, meaning anything that affects early processing must be bottom-up. Thus, not only is Theeuwes' argument circular (bottom-up processes occur early, so early capture must be bottom-up driven), it also ignores any possibility of top-down processing impacting early attentional capture because by definition, early capture relies

on early processing (which must be bottom-up). The assumption of automatic and bottom-up processes being synonymous was noted by Kristjansson (2010) who argues that bottom-up processing is purely saliency-related and that any time an item captures attention not based on physical saliency, must involve top-down processing – no matter how fast or automatic this may be (Kristjansson, 2010).

Another example of a top-down modulation of attentional capture is the contents of working memory. In a series of studies by Humphreys and colleagues it was found that in patients with visual extinction the contents of working memory improves awareness of items usually excluded from awareness (Soto & Humphreys, 2006; Soto et al., 2006). Visual extinction is a neurological disorder wherein patients can only identify an item presented contralaterally to parietal lobe damage in isolation. When such an object is presented alongside an ipsilaterally presented object, patients have no awareness of it. These studies suggest that items matching a working memory template are awarded priority. Although the effects of the contents of working memory mirror the behavioural effects of an attentional bias, it is unlikely that working memory plays a role in the phenomenon. Such involvement would imply that those with an attentional bias continuously hold a template of bias-related items in working memory. However, this is an effortful process that requires the active maintenance of stimuli (Downing & Dodds, 2004; Soto & Humphreys, 2006). Attentional bias is an unconscious deployment of attentional resources and requires no effort, suggesting some other form of top-down alteration of bias-related stimuli is taking place.

Associative learning involving Pavlovian fear conditioning has been found to affect visual attention (Pischek-Simpson, Boschen, Neumann, & Waters, 2009), suggesting it is also has a top-down role in visual attention. Additionally, previously rewarded stimuli can reflexively capture attention when contextually irrelevant to a task (Anderson, Laurent, & Yantis, 2011a, 2011b), and such attentional capture results in altered electrophysiological signatures of attentional selection (Kiss, Driver, & Eimer, 2009). It was argued that this value-driven capture also develops via associative learning and

has been likened to the way that irrelevant drug-related stimuli bias the attention of addicts (Anderson et al., 2011a). This issue of reward is important to note, since additional processing involving the mesolimbic dopamine reward system (see Figure 1.2) may well play an integral role in some maladaptive attentional biases, such as those observed in addiction (Franken, 2003; Franken, Booij, & van den Brink, 2005; Robinson & Berridge, 1993). However, while some attentional biases may involve additional input from the dopamine system, this cannot explain all observed maladaptive biases such as those towards negative items in clinical depression (Gotlib, Krasnoperova, Yue, & Joormann, 2004), or anxiety-related items in generalised anxiety disorder (Armstrong & Olatunji, 2012; Macleod, Mathews, & Tata, 1986; Mogg & Bradley, 2005; Richards, Benson, Donnelly, & Hadwin, 2014). Since attentional biases are present and affect behaviour in comparable ways in many paradigms across a range of populations, this suggests that reward associations may just reinforce an attentional bias after it has already been established via an alternative top-down cognitive mechanism which is common across populations.

This overview of the different ways that visual attention can be modulated indicates that visual attention is a process reliant on the integration of bottom-up and top-down information. One theory that encompasses this integration posits that when first viewing a scene, the vast amount of sensory information is passed through an attentional filter, resulting in a purely bottom-up driven saliency map (Itti & Koch, 2000). This saliency map then interacts with top-down influences such as working memory, learned behaviours, current goals and behavioural relevance to produce a priority map (Awh, Belopolsky, & Theeuwes, 2012; Fecteau & Munoz, 2006). The peaks of the priority map determine the allocation of attentional resources, meaning that both bottom-up and top-down processes have an influence on initial attentional capture.

This framework lends a certain understanding to attentional bias, implying that representations of bias-related stimuli on the priority map have been enhanced in a top-down manner. These top-down alterations then influence the strength of neural activation relating to the stimuli (Awh et al., 2012),

resulting in an involuntary shift of attention towards such items. However, because attentional bias causes the capture of attention by both task relevant (Jones, Macphee, Broomfield, Jones, & Espie, 2005) and task irrelevant items (Stormark, Field, Hugdahl, & Horowitz, 1997), the altering of the stimulus representation on the priority map is involuntary in nature. Thus normally, the allocation of visual attention relies on a carefully balanced interplay between bottom-up stimulus saliency and top-down modulated influences such as behavioural relevance. However with attentional bias, the tipping point between the influence of bottom-up and top-down information has been skewed resulting in involuntary top-down modulations carrying substantially more weight, resulting in the enhanced representation on the priority map triggering a shift of attention even when not the most physically salient or behaviourally relevant.

However, while this explanation appears compelling, the source of the biasing signals remains unknown. One possibility is that the top-down alterations of these signals may be stemming from attentional control settings (Bacon & Egeth, 1994; Folk & Remington, 1998; Folk et al., 1992; Leber & Egeth, 2006b). Attentional settings are an additional top-down modulated mechanism that affects the allocation of visual attention. They can be thought of as internal states that rank incoming information for selection based upon their visual features (Leber & Egeth, 2006a). The existence of these settings was initially laid out in the contingent capture theory (Folk & Remington, 1998, 2010; Folk et al., 1992). This theory states that only objects consistent with a top-down modulated 'attentional set' can capture attention. Folk, Remington and Johnston (1992) discovered that attention is only involuntarily captured by irrelevant items if those irrelevant items share physical properties congruent to behavioural goals (Folk et al., 1992). For example, if searching for a red X, an irrelevant red distractor would capture attention more than a green distractor, since the red distractor shares the colour property of the target. This theory of attentional capture appears to be more harmonious with what is observed in attentional bias – bias related items capture attention even when strictly behaviourally irrelevant. It was initially unclear as to whether top-down capture from attentional settings reflect an enhancement of brain regions that code for bias-related items

(Becker, Folk, & Remington, 2013), or a suppression of non-bias-related items (Navalpakkam & Itti, 2007). However recently, Becker et al. (2013) found evidence suggesting that the similarity (or difference) between targets and distractors is the more critical factor behind the likelihood of a distractor capturing attention, rather than the similarity between distractors and the attentional set.

This theory helps to explain why items relating to the contents of working memory, priming, stimulus associations and reward can all affect the deployment of attentional resources. In their classic paper, Folk et al. (1992) state that "control settings … are a function of current behavioural goals as well as past experiences or enduring biases of [an] organism" (p.1043). Moreover, these attentional control settings do not have to be maintained in working memory (Awh, Vogel, & Oh, 2006; Downing & Dodds, 2004; Houtkamp & Roelfsema, 2006; Olivers, Peters, Houtkamp, & Roelfsema, 2011). This suggests that these top-down mechanisms influence visual attention by altering attentional control settings, such that items relating to these settings are awarded higher peaks on the priority map which causes shifts of attention towards them (Awh et al., 2012; Fecteau & Munoz, 2006). However, while this does explain many findings, it still cannot explain why, in Theeuwes' numerous investigations, the presence of an item not congruent with a top-down behavioural goal managed to capture attention.

A modification of this general theory aimed to integrate the physical properties of objects along with factors resulting from attentional settings in order to explain this. It was argued that attentional settings are used differently depending on which 'search mode' is currently being used (Bacon & Egeth, 1994; Leber & Egeth, 2006b). Bacon and Egeth (1994) proposed the existence of two distinct search modes that viewers can utilise – Singleton Detection Mode or Feature Search Mode – the selection of which is under top-down control and relies on which mode offers optimal performance. Singleton Detection Mode appears to be the default settings, and is based purely on physical salience with the most salient item capturing attention (Bacon & Egeth, 1994; Kawahara, 2010). This mode is consistent with Theeuwes' findings, thus in these experiments, Singleton Detection Mode

was activated via top-down control. The selection of Singleton Detection Mode is inconsistent with attentional bias, since bias-related may not be the most physically salient. Alternatively, Feature Search Mode relies on a defining target feature – such as a particular colour – and is a much narrower attentional setting that results in a reduction of interference from salient objects that do not share the defining target feature. The top-down activation of this mode explains findings relating to the contents of working memory on attentional capture and appears more consistent with attentional bias, as a mode for food-related items could be activated at lunch, reducing interference from non-food-related items causing a Burger King sign on a busy street to capture attention.

The allocation of visual attention is therefore based on a balance between the bottom-up properties of objects and the top-down mediated attentional settings of an individual. This model suggests that an attentional bias occurs when there is increased weight of top-down factors that causes shifts of attention towards bias-related information. However, empirical evidence for this is lacking. Currently, information relating to the cognitive basis of attentional bias must either be extrapolated from cognitive investigations of visual attention, or from studies of maladaptive biases in abnormal populations. However, cognitive studies do not specifically investigate attentional bias. Instead, these experiments are designed to assess the merits of various theoretical models of visual attention, and results from these studies are used to influence these models. Similarly, investigations of maladaptive biases do not specifically examine the cognitive aspects of attentional bias. Here, attentional biases are studied in abnormal populations when a bias of attention towards certain information can be harmful (Bearre et al., 2007; Field & Eastwood, 2005; Sharma et al., 2001). While these investigations have provided a vast amount of information regarding the presentation of attentional bias within abnormal populations, explanations of attentional biases from these investigations are heavily influenced by the nature of each specific bias. Furthermore, there are no strict control measures in place relating to the tasks used, the populations investigated, or control groups used to compare findings to. Consequently, in order to gain a better understanding of the

cognitive basis of attentional bias, a specific investigation of attentional bias in a normative population using an appropriate task is required.

1.3 Investigations of Maladaptive Biases

Thus far, evidence has been presented from the cognitive literature that supports the argument that an attentional bias occurs when the tipping point between top-down and bottom-up sources of information on the priority map has been skewed resulting in top-down modulations carrying disproportionate weight. However, since attentional bias has not been directly investigated from a cognitive perspective, this evidence has been inferred from cognitive explorations of attention, rather than investigations of attentional bias. The only investigations of attentional bias per se, have been conducted in the abnormal arena. This section of the General Introduction shall therefore present evidence supporting this argument of skewed representations on the priority map from investigations of maladaptive biases within discrete abnormal populations.

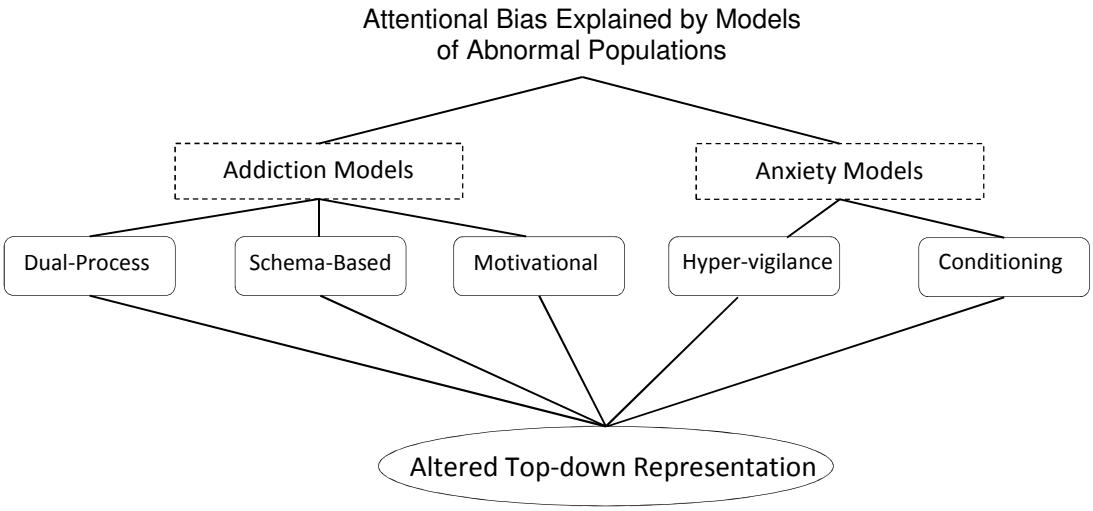

Figure 1.1: **Overview of Models of Abnormal Behaviours.** An overview of the various models of abnormal behaviours that offer evidence of a cognitive mechanism of attentional bias. Models from both the addiction and anxiety literatures suggest attentional bias develops to serve a common goal of satisfying behavioural goals. Population-specific behaviours then form after attention has been biased towards pathology-related information.

The two most common maladaptive biases currently investigated relate to either addiction or anxiety. Within the addiction literature, several theories exist suggesting how attentional bias develops and the mechanisms that both support and sustain this development. These include dual-

process models (Robinson & Berridge, 1993; Tiffany, 1990), schema-based theories (Tiffany, 1990) and motivational theories (Wiers et al., 2007). Each theory offers differing explanations of the development and involvement of attentional bias, however despite this, all also provide evidence to suggest that the influence of top-down information on the priority map has become magnified.

Dual-process models suggest that addictive behaviours arise as a result of automatic/spontaneous and reflective/considered processes (Robinson & Berridge, 1993; Tiffany, 1990). Automatic processes are fast and occur against conscious will (Ryan, 2002). In contrast, reflective processes are slow, relate to conscious will and involve executing functioning and cognitive control – such as Alcohol Outcome Expectancies (Brown, Goldman, Inn, & Anderson, 1980; Jones & Mcmahon, 1994). Attentional bias is an example of an automatic process (Cox, Blount, & Rozak, 2000; Payne, McClernon, & Dobbins, 2007). Once bias-related items effortlessly attract attention, reflective processes – such as cognitive control – are required if these items are not behaviourally relevant. However in addicted populations, this processes is also disrupted (Robinson & Berridge, 1993, 2000, 2008) resulting in bias-related information having an even greater impact on behaviour. Dual process models therefore suggest that attentional biases develop swiftly, unconsciously and automatically, and can be reinforced via deficiencies in executive functioning and cognitive control. However, while this suggests that biases can quickly develop, they do not provide any evidence for the stage of addition that the development of the attentional bias occurs, nor exactly how quickly the attentional biases develop in the first place.

Robinson and Berridge's Incentive-Sensitisation theory (Robinson & Berridge, 1993, 2000, 2008) develops this further, placing the emphasis on the neurobiology of craving, and how this relates to increased salience of drug-related cues. However, while Robinson and Berridge use the word "salience", the actual bottom-up signals of incoming information is not altered; thus what Robinson and Berridge refer to as 'saliency' is actually altered top-down representations on the priority map. The Incentive-Sensitisation theory states that when a drug is used, it elicits a reward-based

mesotelencephalic dopamine response – see Figure 1.2 (Wise & Bozarth, 1987). Through continued use, this dopamine response becomes hypersensitive resulting in a psychological effect of increased incentive to use. Top-down representations of drug-related cues on the priority map via mental representations of the mesotelencephalic dopamine response are then enhanced (incentive salience). Ultimately, Robinson and Berridge argue that this cyclic response transforms drug 'liking' to drug 'wanting' – the driving force behind craving and relapse.

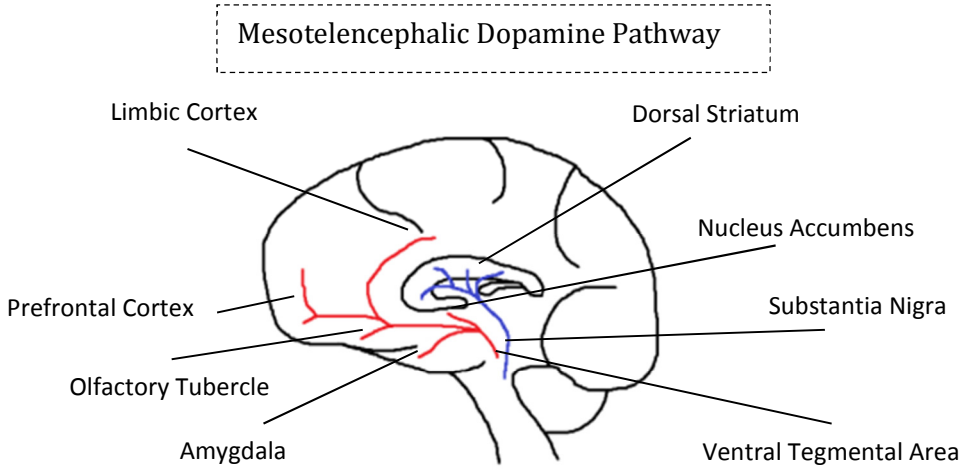

Figure 1.2: **The Mesotelencephalic Dopamine Pathway.** A figure showing the mesotelencephalic dopamine system, comprising the mesocorticolimbic pathway (depicted in red) and the nigostriatal pathway (depicted in blue).

This theory therefore suggests that attentional settings that prioritise drug-related objects are the result of reward-based involvement of the mesolimbic dopamine system. Only after repeated exposure to substances (and repeated dopamine responses) are top-down representations of drug-related cues enhanced. However, while this argument successfully links biases of attention with a neural response, it cannot explain the mechanisms of the initial development of attentional biases (particularly since dual-process models suggest this development can be swift), nor can it explain pathological anxiety-based biases of attention since anxiety is a negative emotion that humans avoid if possible (Reiss, 1991). It is therefore probable that reward associations may reinforce biases after they have already developed. This initial development would be via an alternative top-down cognitive mechanism which is common across pathological groups. If so, the capture of attention in

attentional bias would be common to all populations, however the sustainability and reinforcement of attentional bias may be pathology- (and population-) specific. Attentional biases may reflect the adoption of an attentional setting that is initially formed in order to satisfy a behavioural goal, either non-regulatory (to obtain drugs) or regulatory (to avoid threat). Once this attentional setting is established and pathology-related information begins to capture attention, the biases are reinforced by the strong pathology-specific reactions to the information (reward/fear). This would suggest that the weighting of top-down information on the priority map can also continuously increase as the biases are reinforced.

Tiffany's (1990) schema-based theory also suggests that altered top-down representations of addiction-related information on the priority map are the driving force behind attentional biases. This theory suggests that pathology-related cues are processed as highly salient (but: see above for the use of the word 'salient') because substance users actively process substance-related cues to fulfil a schema to reduce craving. This suggests that the activation of these schemas only occurs after sufficient experience with drugs, suggesting (as Robinson and Berridge) that internal attentional settings favouring drug-related cues do not develop instantaneously (Tiffany, 1990). It also suggests that the attentional settings have to be externally cued (via a situation, an object or a particular environment). This would mean that attentional biases are the result of an attentional setting that is easily activated following the initiation of an underlying schema (Cosman & Vecera, 2013). However, this explanation does not hold since attentional biases serve to achieve internally established behavioural goals, whereas these schemas are only activated after drug-related stimuli have already captured attention. Consequently, Tiffany's explanation would state that addiction occurs before attentional bias, yet it is more likely that the schemas are triggered *after* the establishment of an attentional bias. Thus, the altered impact of top-down information on the priority map occurs first, followed by the addiction-related schemas and resulting behaviours. However the precise mechanics of how and when the tipping point between the bottom-up and top-down information becomes skewed is unknown.

Finally, Wiers et al.'s 2007 adolescence-specific model states that addictive behaviours develop via a two-phase system consisting of the ability to stop use but no motivation to do so, followed by increased motivation to use with less ability to stop (Wiers et al., 2007). The first phase encompasses the reflective processes discussed earlier (cognitive control, executive functioning), whereas the second phase involves automatic processes, including attentional biases (Ryan, 2002). This suggests that attentional biases form gradually over time until the increased motivation to use creates an automatic process of addiction-related items being preferentially selected for further processing. As individuals use more illicit substances, the will to increase use is further magnified. This increase in use could be the point at which the top-down information relating to reward and associative learning carries more weight on the priority map than bottom-up information, resulting in an attentional bias. However, whilst this potentially bridges the gap between an addiction-model of attentional bias development and the cognitive literature of the origin of the bias, it can only give a vague answer of *when* the attentional settings are changed. Moreover, it cannot answer the question of just *how* the attentional settings are altered in the first place.

Furthermore, the initial motivation to use would create a behavioural goal to seek drugs, suggesting that an attentional bias actually forms early in addiction (since attentional biases are the mechanism used by the autonomic nervous system to achieve and/or satisfy behavioural goals). It is possible that the automatic processes, instead of reflecting the development of an attentional bias, reflect the lack of control that can be exhibited over drug-related cues after they have already captured attention. This would mean that the formation of an attentional bias occurs first, followed by the pathology-specific aspects of addiction. In other words, bias-related attentional capture occurs at an early stage of addictive behaviour, suggesting the mechanism relating to this initial capture (altered weight of top-down information on the priority map) is the underlying cognitive basis of attentional bias. This could be empirically tested by examining if it is possible to induce an attentional bias towards an arbitrary stimulus via a single mechanism, thus removing reward, schema activations and emotional responses that form a key aspect of current theories of maladaptive biases. If so, this

would provide evidence that the initial capture of attention can occur before pathology-specific aspects of attentional bias, and does not require repeated exposure to a substance and/or situation.

Within the anxiety literature, one theory of attentional bias surrounds hyper-vigilance for anxiety-related items in order to monitor for potential threats or dangers (Armstrong & Olatunji, 2012; Richards et al., 2014). Recently, Richards et al. (2014) attempted to connect the classic attention literature and pathological attentional bias literature with an emphasis on the oculormotor system. However, instead of examining attentional bias as a whole, the paper focuses purely on how anxiety-related attentional biases relate to what is currently known about attention. Here, Richards et al. suggest that having a selective bias for threat, and being hyper-vigilant of threat-related items are in fact distinct attentional biases (Richards et al., 2014). They propose that a selective attention for threat-related items is characterised by a failure to make an eye-movement away from threatening items once they have captured attention (Gerdes, Alpers, & Pauli, 2008). This is distinct from hyper-vigilance for threat-related items, which is characterised by excessive scanning eye-movements over a visual scene (Horley, Williams, Gonsalvez, & Gordon, 2004).

This suggests that attentional biases are closely related both to the initial capture of and inability to disengage attention from bias-related items (Posner & Petersen, 1990). However, while Richards et al. (2014) do endeavour to link the clinical bias literature with cognitive attention literature, it suffers from a similar pitfall of the addiction-related models in that it fails to explain how attention was captured by the bias-related items in the first place. Richards et al. does suggest this is in part due to those with high trait anxiety making more scanning eye-movements than healthy controls; however with no links between the various different types of pathological attentional biases it is difficult to state with certainty if this is the driving force behind all attentional biases. Moreover, the reasoning behind these excessive eye-movements is unclear. It is possible that those with anxiety have a constant behavioural goal to avoid threat, which creates an attentional setting prioritising threat-related items for further processing. Representations of threat-related items on the priority map

would therefore be modulated in a top-down way via the attentional set. It also suggests that the inability to disengage attention from such objects does not reflect an attentional bias per se, but a behaviour that results from the attentional bias (mirroring what is observed in addicted populations). This provides more evidence that there is a common cognitive basis of attentional bias resulting from the altered weight of top-down information on the priority map – most likely stemming from an attentional setting to achieve a behavioural goal. This altered weight then results in the pathology-specific behaviours (excessive eye movements and difficulty disengaging attention).

Some research has speculated that anxiety-related attentional biases originate from conditioning, wherein a previously unrelated object and an unpleasant sensation (i.e., fear or anxiety) co-occur to the extent that the object now elicits the unpleasant response (Dawson, Beers, Schell, & Kelly, 1982; Van Damme, Crombez, Hermans, Koster, & Eccleston, 2006; Van Damme et al., 2004). The desire to avoid confrontation with the conditioned stimulus results in hyper-vigilance, which in turn has the paradoxical effect of making it more likely that the stimulus will be detected resulting in increased negative responses and heightened anxiety (Eysenck & Byrne, 1994; Mogg, Bradley, Hyare, & Lee, 1998; Van Damme et al., 2006). However, since the anxiety and attentional setting literature have yet to interact, it is difficult to ascertain if this is occurring. Moreover, this may well be merely a different level of the above explanation. Nevertheless, this once again places the emphasis on altered representation of top-down information that prioritises information based on goals and behavioural relevance, potentially via altered attentional settings (Bacon & Egeth, 1994; Folk & Remington, 1998; Folk et al., 1992; Leber & Egeth, 2006b).

What is clear is that evidence from both addiction and anxiety both support the notion that there is a common cognitive mechanism involved in attentional bias, and that a likely candidate is attentional control settings that are altered to satisfy a behavioural goal. These result in incoming information relating to these settings affecting the boundary limits of the representation of top-down and bottom-up information on the priority map. It is only when items relating to pathology

consistently and persistently capture attention that the unique pathological behaviours are built. This explains why various abnormal populations all exhibit comparable evidence of their attentional biases in many different tasks, yet also explains why each population goes on to exhibit different behaviours (avoidance with anxiety, approach with addiction). The attentional biases are all driven by attentional control settings, whereas the behaviours built upon these settings are driven by different behavioural goals. Further evidence to support this could stem from common patterns of neuronal activation displayed in both abnormal and normative populations to attentional tasks.

1.4 Neurological Basis

Literature on the neurobiology of attention using normative populations suggests that when items are visually selected for further processing in a top-down manner, a dorsal frontal-parietal neural network involving the dorsolateral prefrontal cortex (DLPFC), the intraparietal sulcus (IPS), superior parietal lobule (SPL), the frontal eye fields (FEF) and the supplementary eye fields (SEF) is activated (Corbetta, Kincade, & Shulman, 2002; Corbetta, Miezin, Shulman, & Petersen, 1993; Corbetta & Shulman, 2002; Gitelman et al., 1999; Gogtay et al., 2004; Kastner, Pinsk, De Weerd, Desimone, & Ungerleider, 1999; Peelen, Heslenfeld, & Theeuwes, 2004; Ptak, 2012; Reynolds & Chelazzi, 2004; Walsh & Cowey, 2000). For example, Hopfinger, Buonocore and Mangun (Hopfinger et al., 2000) found via fMRI that in response to instructive cues, there was activation in the IPS, SPL, FEF and the posterior cingulate cortex (PCC). These regions were not active when the same cues were not relevant to task demands. Also using fMRI, Corbetta et al. (2002) found that when participants voluntarily orient attention towards a particular visual cue there is heightened activity in the ventral, dorsal and anterior IPS, as well as the FEF.

These findings have been repeatedly corroborated (Asplund, Todd, Snyder, & Marois, 2010; Corbetta & Shulman, 2002; Yantis et al., 2002), with an implicated role of the SEF in shifting the location of visual attention (Liu, Slotnick, Serences, & Yantis, 2003; Shomstein & Yantis, 2004). Furthermore, a review of the literature supports the role of the IPS and FEF for top-down control of object-based and spatial attention (Corbetta & Shulman, 2002). These findings support the notion that this

frontal-parietal network allows for the voluntary selection of visual stimuli based upon items relating to the current goals of an individual, including the contents of working memory (Awh & Jonides, 2001; Gazzaley & Nobre, 2012) and the current attentional set. Thus, this frontal-parietal network may be involved in attentional biases that arise out of an attentional setting to satisfy a behavioural goal (Bacon & Egeth, 1994; Corbetta & Shulman, 2002; Folk et al., 1992; Leber & Egeth, 2006b).

Another region believed to be crucial when orienting attention to behaviourally relevant information is the prefrontal cortex (PFC). One role of the PFC has been described as "maintaining representations that guide control of tasks" (Herd, Banich, & O'Reilly, 2006; p. 22). Findings from single cell recordings in the monkey lateral PFC show that the PFC is involved in regulating motivationally-relevant information (Watanabe, Hikosaka, Sakagami, & Shirakawa, 2002). Furthermore in their review of the literature on the role of the PFC in addiction, Goldstein and Volkow (2011) suggest that due to the PFC's involvement in attention and the formation and switching of attentional settings, it may also be implicated in directing and maintaining attention towards bias-related items and away from non-bias-related items as they are not deemed task-relevant (when they may actually be). Thus, it appears as though the PFC contributes to attentional bias in two important and supplementary ways. Firstly, it is involved in forming and implementing the attentional settings that prioritise bias-related information in a top-down manner, and secondly it plays a role in maintaining these control settings which in turn exerts control over tasks. If the PFC establishes attentional settings prioritising biasing information, this suggests that such information would then be categorised as task-relevant, decreasing the likelihood that attention will be disengaged from these items and onto items that are actually task-relevant.

Findings from Stroop tasks in both normative and abnormal populations offer support for the involvement of the PFC in maintaining attention towards task-relevant information. In the original form of the Stroop task, names of colours are presented in a variety of coloured ink and participants have to name the colour of the ink rather than the word (Stroop, 1935). It is believed that the

semantic quality of the word unconsciously interferes with perceptual processing of the ink, causing delays in reaction times for incongruent word/colour combinations (Logan, 1980; Tzelgov, Porat, & Henik, 1997). Using this task, lower PFC activation has been consistently found to coincide with increased reaction times towards incongruent colour/word pairings in healthy populations (Banich et al., 2000; Nestor, Ghahremani, Monterosso, & London, 2011; Zysset, Muller, Lohmann, & von Cramon, 2001).

Modified versions of the Stroop investigating attentional bias in abnormal populations work in a similar way. Pathology-related words are presented in a variety of different colours and again, participants are required to name the ink, not the word. Reaction times are greatly increased whenever participants with an attentional bias have to name the colour of bias-related words compared to neutral words. In neuroimaging studies, increased reaction times towards bias-related words are also associated with a reduction in activity of the PFC (Nestor et al., 2011), suggesting that the PFC is less able to exert control over the primary aims of the task – report the colour of the word – resulting in greater interference from the semantic bias-related qualities of the words increasing reaction times. Additionally, greater activation in the PFC is observed when participants successfully ignore the semantic qualities of bias-related words (Fales et al., 2008; Wagner et al., 2006).

This latter finding relates to a further important role of the PFC in visual attention and attentional bias. In order to ensure that visual attentional is not unnecessarily captured or utilised by irrelevant objects inharmonious with current goals, some form of controlling cognition is thought to be involved (Corbetta & Shulman, 2002). Cognitive control has been defined as “the provision of top-down support for task-relevant processes” (MacDonald, Cohen, Stenger, & Carter, 2000) (p. 1836). The dorsolateral PFC (DLPFC) is thought to play an authoritative role allowing for the executive and cognitive control of the environment and incoming visual stimuli. Several studies have shown that DLPFC activity increases during demanding tasks that require focused attention (Cabeza & Nyberg, 2000; M. D. Fox et al., 2005; Gerlach, Spreng, Gilmore, & Schacter, 2011). Lesioning the PFC also

causes deficits in the executive control of attention (Rossi, Pessoa, Desimone, & Ungerleider, 2009). Moreover, the DLPFC has been implicated in various aspects of cognitive control, including problem solving (Gerlach et al., 2011), conflict monitoring (Goldstein, Alia-Klein, et al., 2009), and the coordination of behaviour based upon current goals or task demands (Koechlin, Ody, & Kouneiher, 2003). The role of the DLPFC is also observed across various paradigms believed to involve cognitive control, such as the delayed match-to-sample WM (Walter, Wolf, Spitzer, & Vasic, 2007) and digit-sorting tasks (Siegle, Thompson, Carter, Steinhauer, & Thase, 2007).

However, PFC activation in abnormal groups reflecting more control required for additional semantic interference raises an important issue when the neurobiology of attentional bias is examined in non-normative samples. Findings in such investigations may not directly reflect the cognitive mechanisms of attentional bias, but instead may reflect pathology-specific processing that occurs after attention has been captured by pathology-related stimuli. For example, one issue of attentional bias that is touched upon in Wiers et al.'s (2007) model discussed above is the role that cognitive control plays when discerning what objects to pay attention to and which to ignore. However, this cognitive control would only be implemented after attention has already been biased towards irrelevant bias-related information. As mentioned, dual-process models of addiction stress the interplay between automatic and reflective processing. Attentional bias is widely accepted to be an example of an automatic process (Bruce & Jones, 2006). In contrast, reflective processes relate to executive functioning and cognitive control. Thus, reflective processes are believed to mediate the effect that automatic processes have on behaviour (Robinson & Berridge, 1993; Tiffany, 1990). This suggests that the better the cognitive control, the less of an impact an attentional bias will have on subsequent behaviour.

This role of the PFC in reflective processing via the control of behaviour following the capture of attention by bias-related information is supported by several neuroimaging studies involving pathological attentional biases. For example, Hester and Garavan (2009) conducted a study primarily

investigating the role of the mesocorticolimbic reward system in cocaine users. They found when cocaine users carried out a task superimposed on an irrelevant cocaine-related background and when working memory load was also high, that there was activity in the right inferior frontal gyrus – an area associated with cognitive control – suggesting users had to demonstrate greater control over the attentional bias towards the drug-related background image in order to focus on the demanding task. Thus, not only did it appear that attention was biased towards the cocaine-related background (participants showed an attentional bias for the irrelevant cocaine-related information), but following this capture of attention, additional neural resources were required to keep participants on task. This finding has been verified in a variety of additional neuroimaging studies, also with cocaine users. Typical patterns of activity involve hypoactivity in areas related to cognitive control; the left anterior cingulate cortex or ACC (Bolla et al., 2004; Hester & Garavan, 2004), the prefrontal cortex (Bolla et al., 2003; Bolla et al., 2004; Hester & Garavan, 2004) and hyperactivity in the orbitofrontal cortex for attention-demanding tasks (Goldstein, Volkow, Wang, Fowler, & Rajaram, 2001). Again, this suggests that after attention has been captured by attentional bias-related information, additional processing is required in abnormal populations to counter distractions caused by this information.

These neuroimaging tasks using abnormal populations therefore offer unclear information on the cognitive basis of attentional bias since data regarding additional processing following the effects of the attentional biases is produced. Moreover, these studies suggest that individuals with reduced executive control may be more susceptible to forming attentional biases in the first place, since they are less able to control the automatic orienting of attention towards substance-related items. In other words, with lower executive functioning, it is possible that the adoption of attentional settings occurs much faster as there is less control over the behavioural urge to begin with. This is further highlighted by Hester and Garavan (2009); there is no way of knowing if the increase in cognitive control following attentional deployment to attentional bias-related information was due to the cognitive aspect of the attentional bias, craving, or the control of automatically activated action. This

uncertainty is intensified since the study lacked a control group of non-addicts to compare activation to. In addition, while this study did stress increased saliency of certain stimuli for cocaine users, the focus on the mesocorticolimbic system through the rewarding properties of cocaine confound results yet further because – as mentioned – attentional biases are found in clinical groups without rewarding side-effects of their bias-related stimuli (i.e., anxiety). Thus, the abnormal population used to investigate attentional bias directly impacted on what was concluded about attentional bias – despite the possibility that the results may not be directly related. These result in data that is difficult to interpret with respect to the cognitive mechanisms underlying attentional bias.

This lack of a control group was noted by Luijten et al. (2011), who again tested attentional bias using an addicted population of smokers. Smokers and non-smokers were examined with a novel attentional bias line counting task alongside fMRI (Luijten et al., 2011). The possible role of the ACC in attentional bias, originally suggested by Franken (2003) was supported, with hyperactivity in the dorsal ACC, the right superior parietal lobe and the left superior temporal gyrus observed (Franken, 2003; Luijten et al., 2011). Additionally, hypoactivity was observed in the rostral-ventral ACC; consistent with findings from Goldstein and colleagues (Goldstein, Alia-Klein, et al., 2009). It was argued that the dorsal ACC is involved in monitoring the conflict between the cognitive demands of the task, and the automatic allocation of attention towards the attentional bias-related smoking images, supporting evidence from previous studies (Botvinick, Cohen, & Carter, 2004; Egner, Etkin, Gale, & Hirsch, 2008). It suggests that smokers required even further top-down control over the allocation of attention to counteract the biasing effects of the substance-related images.

However, yet again there is a problem with using this sub-group, as the ACC activation could be due to controlling the urges and cravings of smokers to smoke when presented with smoking-related stimuli. As stressed, this craving would occur *after* attention has already been captured by the smoking-related stimuli and as such, this study cannot provide clear information regarding the neural basis of the cognitive mechanisms of attentional bias. If this task was replicated using a

normative sample with an attentional bias towards an arbitrary stimulus, it is possible that no ACC activation would be present, thus demonstrating once more the issues that occur when investigating the cognitive phenomenon of attentional bias with abnormal populations and emotive stimuli. This is one issue that shall be addressed throughout this thesis where the emphasis will be placed on using healthy participants and examining induced attentional biases to arbitrary stimuli.

Furthermore, the activation of the ACC raises an important point in that while both the DLPFC and ACC have established roles in the cognitive control of attention and behaviour, there is a double dissociation between their precise functions (MacDonald et al., 2000). MacDonald et al. (2000) discovered that during the preparation of a Stroop-type task, the left DLPFC appeared to play a role in the implementation of control over naming the colour of a word. On the other hand, the ACC showed heightened activity when confronted with incongruent word/colour pairs, suggesting it was more involved with resolving incongruent task conflicts. Thus, while both the ACC and DLPFC play a role in the overall cognitive control of attention, ACC activation is consistently found when conflicts are present (Botvinick, Braver, Barch, Carter, & Cohen, 2001; Carter et al., 1998; Kerns et al., 2004), whereas PFC activation appears more related to acting upon these conflicts (De Pisapia & Braver, 2006; Egner, 2011; Haddon & Killcross, 2006). Furthermore, there is evidence suggesting that the initial source of early-visual neuronal competition (i.e., areas V1, V2, V4) in favour of a particular stimulus property or set of properties – the attentional set – is the prefrontal cortex (Beck & Kastner, 2007, 2009; Funahashi, 2006; Yantis, 2008). This suggests not only that the prefrontal cortex is related to cognitive control, but that it also plays a role in the initial selection of objects for further attentional processing by biasing the activity of neurons that selectively code for particular visual features (Desimone & Duncan, 1995). Whether this activation is more associated with initially establishing the attentional settings or maintaining the attentional settings remains unclear, although some recent studies using neurostimulatory techniques such as Transcranial Magnetic Stimulation (TMS) and Transcranial Direct Current Stimulation (tDCS) have attempted to investigate this.

Leyman, De Raedt, Vanderhasselt and Baeken (2011) found that high-frequency repetitive-pulse TMS (rTMS) over the left DLPFC in clinically depressed patients with attentional biases towards negative information resulted in an improvement of the active suppression of the negative information and thus, a suppression of their attentional biases (Leyman, De Raedt, Vanderhasselt, & Baeken, 2011). However, this finding was only observed after a 10-day period of this stimulation – no effect was observed in the processing of negative cues after a single session. It was proposed that the transient effects of one sessions of high-frequency rTMS is not sufficient to alter blood flow and metabolism in the DLPFC, yet repeated sessions of rTMS are (Luborzewski et al., 2007). This suggests that the PFC – in response to the conflict alerted via the ACC – continuously updated attentional settings in order to favour more task-relevant items; a process which is believed to occur whilst suppressing distracting qualities of irrelevant bias-related items. This suggests a role of the PFC in the cognitive mechanisms underlying attentional bias, as it points to a role of the updating of attentional control settings. Moreover, this finding supports the role of the PFC proposed by Watanbe et al. (2002) and Goldstein and Volkow (2011), who also argued that the PFC plays a role in the formation and switching of attentional settings, and as such, in the implementation of a stimulus-specific type of Feature Search Mode that may be the cognitive mechanism of attentional bias.

Likewise, studies using tDCS have found that increasing the excitability of the left DLPFC in patients with Major Depressive Disorder not only enhanced patients' working memory performance, but also ameliorated their attentional bias towards negative stimuli (Wolkenstein & Plewnia, 2013). This suggests that when confronted with a conflict between task-relevant information, and irrelevant attentional-bias related information, the PFC plays a crucial role in suppressing the irrelevant bias-related information while increasing the processing of information pertinent to task goals. However, whether this finding relates to greater cognitive control or the updating of the attentional setting remains unclear. A further issue is that both Wolkenstein and Plewnia (2013) and Leyman et al. (2011) used abnormal samples of depressed patients alongside emotive stimuli. Thus, findings are

difficult to attribute to the normative population, since it is unknown if the conflict arose from the emotive-qualities of the stimuli eliciting irrelevant amygdala activation that disrupted behaviour, or if it was originally due to attentional control settings favouring the negative stimuli. Removing pathology from the investigation to examine if the PFC is critically involved with attentional bias free from these confounds would enable this link to be more directly investigated.

Studies from the abnormal literature therefore do not provide clear information on the neural basis of the cognitive mechanism of attentional bias, and thus do not provide substantiate evidence to suggest that a cognitive basis of attentional bias is an adopted attentional control setting which skews the balance of incoming information related onto the priority map. Findings may reflect the required cognitive control of participants' craving for drugs when presented with drug-related stimuli in addiction – a process that occurs after the effects of attentional bias. Alternatively, findings may relate to additional amygdala activity when emotional information is processed in those suffering from emotional disorders and the related attentional biases towards emotional information – processes that also occur following the initial effects of attentional bias (i.e., the initial allocation of attention). These issues would not occur if attentional bias was being investigated independently of pathology, for example if healthy participants were being presented with a meaningless stimulus that they have an attentional biases induced towards. At present, such investigations have yet to occur.

1.5 Methodological Review

Current methodologies used to investigate the presence and degree of attentional biases range considerably, but all stem from the premise that the presence of a bias-related stimulus will cause attention to be allocated towards the processing of that stimulus, disrupting or altering the way in which a participant would normally behave (see Figure 1.3). The wide variety of available paradigms, such as the Stroop, Dot-Probe and Dual Task paradigms, all suggest that attentional bias is a robust phenomenon – since it consistently affects behaviours across a range of testing environments. However, this range of testing paradigms also results in unhelpful implications regarding the

interpretation of data, as we do not know which process (or processes) are being affected by attentional biases.

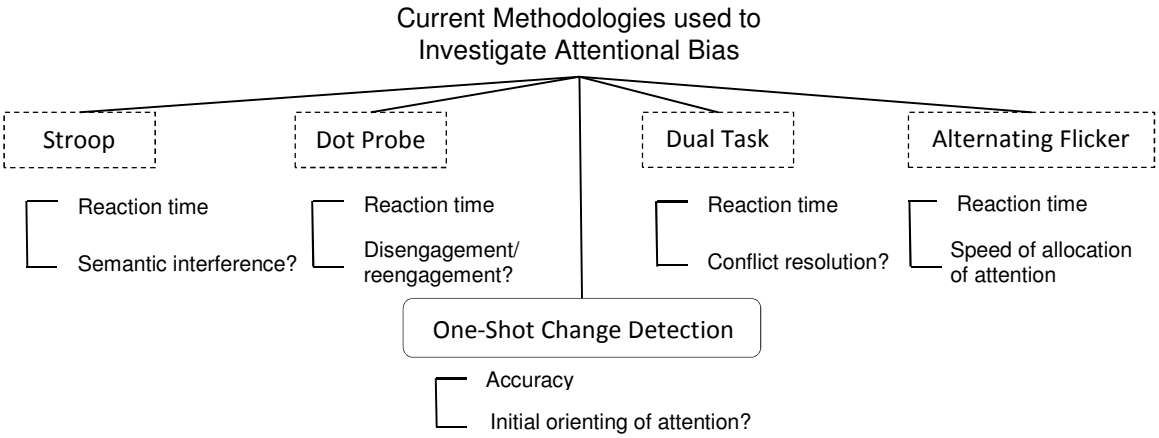

Figure 1.3: **Methodological Approaches to Studying Attentional Bias.** An overview of the various methodological approaches to studying attentional bias. Currently, the Stroop, Dot Probe, Dual Task and Alternating Flicker tasks are widely used, however the One-Shot Change Detection Task may offer a better alternative.

As a consequence, it is difficult to state with certainty how the visual and attentional systems are prioritising certain items for processing over others. This is especially problematic with certain paradigms, where findings cannot be directly applied to the allocation of attention and instead may be due to emotional interference or the triggering of associated memories. A further issue is that it is also difficult to examine the cognitive mechanisms of attentional bias, as each paradigm arguably investigates a different cognitive mechanism and not only have these flawed methodologies been used, but they have been used in conjunction with non-normative populations. It is therefore necessary to review the current methodologies used in the study of attentional bias and what findings from these suggest about the cognitive mechanisms of the phenomena before ascertaining which is the most appropriate to use.

The most commonly used paradigm to examine attentional bias is a modified version of the classic Stroop task, developed by John Ridley Stroop in 1935. Pages 34-35 of this thesis outline both the classic and modified versions of the Stroop task. Using the modified Stroop, delays in reaction times have been found in those with alcohol problems to alcohol-related words (Lusher, Chandler, & Ball,

2004), anxiety problems to anxiety-related words (Carter, Maddock, & Magliozzi, 1992), general drug abuse problems to drug-related words (Carpenter, Schreiber, Church, & McDowell, 2006; Gardini, Caffarra, & Venneri, 2009) and heroin addicts to heroin-related words (Marissen et al., 2006). This similarity in findings across a range of abnormal populations points towards a common mechanism driving the delay in reaction time and it has been argued that this mechanism is an attentional bias towards the pathology-related words over neutral words. Moreover, the fact that researchers investigating attentional bias within these different abnormal populations all argue that it is the same attentional bias driving the reaction time delays (Bauer & Cox, 1998; Boyer & Dickerson, 2003; Hallgren & McCrady, 2013; Hester, Dixon & Garavan, 2006; Johnsen, Laberg, Cox, Vaksdal & Hugdahl, 1994; Lusher, Chandler & Ball, 2004) also suggests a mechanism of attentional bias that is common to all populations that exhibit one. However, despite findings from Stroop tasks used to make inferences regarding attentional bias, the Stroop task is not a direct measure of the allocation of attention. Instead, the Stroop task measures a delay in articulating the colour of a word; the actual processes responsible for this delay are relatively unknown (Algom, Chajut, & Lev, 2004; J. D. Cohen, Dunbar, & Mcclelland, 1990; C. M. Macleod, 1991).

One possibility is that certain words carry with them extra emotional charge to some people, and the activation of this emotion causes delays in processing the colour of the ink, consequently delaying response times (Bauer & Cox, 1998). If this is the case, the Stroop effect relates to emotional saliency, not attentional bias and findings from Stroop tasks cannot be attributed to the effects of biased visual attention. Findings do suggest that abnormal populations all have issues with emotional saliency when processing pathology-related words, but it is unknown from these tasks if attention is initially captured by the pathology-related words before the increase in emotional processing, or if this increased processing occurs after attention has allocated at a later stage. Due to this uncertainty on exactly when attention is allocated to pathology-related words, using the modified Stroop to examine attentional bias is inappropriate.

An alternative methodology commonly employed to investigate attentional bias uses a novel version of a Dual Task paradigm (Waters & Green, 2003). In Waters and Green (2003), participants completed two simultaneous tasks – one in the centre of a screen, and one out of the corner of their eye. Centrally, the task was to decide if a number was odd or even. At the same time, words or non-words were shown to the periphery. Participants were asked to make a lexical decision regarding if the presented text was a word or a non-word. Accuracy and reaction time on the odd/even task was taken as an indicator for the presence of an attentional bias. Waters and Green (2003) found that if the peripheral text was alcohol-related, recovering alcoholics had more errors and were slower at the odd/even task than if neutral words were shown. They were also slower and more inaccurate compared to healthy controls when the peripheral word was alcohol-related.

Waters and Green (2003) argued that this was due to the recovering alcoholics' attention being captured by the semantic qualities of the alcohol-related words, diverting processing away from the central odd/even task. However, while this task does suggest interference from alcohol-related stimuli in recovering alcoholics, again it is not a direct measure of attention or of the capture of attention. It is unknown in this task if attention was initially captured by the alcohol-related words, or if it was difficult to disengage attention from the words once it had been captured. Thus, these findings could also relate to the semantic qualities of words resulting in a potential emotional response that interferes with other tasks and slows reaction times. Alternatively, the dual-task paradigm could produce a measurement of the additional automatic processing that occurs in recovering alcoholics in the presence of alcohol-related stimuli – be these attentional processes or processes triggered by the emotional saliency of alcohol-related words. This ambiguity once again indicates an inappropriate paradigm to test for the cognitive mechanisms of attentional bias, since it may not be biased visual attention that is being investigated.

The issues with indirect measures of attention have spurred many researchers to adopt an alternative methodology; namely the dot probe paradigm (Macleod et al., 1986; Townshend & Duka, 2001). During dot-probe tasks that investigate attentional bias, participants view two words or images simultaneously displayed on opposite sides of a computer screen. These are then followed in some trials by a dot on only one side of the screen that participants are required to respond to. The task is to react when a dot appears as quickly and accurately as possible, indicating on which side of the screen the dot appeared. Response times for those with an attentional bias have been found to be significantly different depending on if the location of the dot is congruent or incongruent to the location of bias-related (i.e., pathology-related) stimuli. Faster reaction times are observed when the dot and bias-related stimuli are congruent and vice versa, arguably due to attention being captured by the stimulus in question (Ehrman et al., 2002; Field, Mogg, Zetteler, & Bradley, 2004; Lubman, Peters, Mogg, Bradley, & Deakin, 2000).

However once again, the dot-probe paradigm may not be a direct measure of the biasing of visual attention. As observed by others (Fox, Russo, & Dutton, 2002), behaviour in the dot probe task may stem from multiple sources. These include faster initial capture of attention (attentional bias), an increase in the sustainability of attention, or the inability to disengage attention from the bias-related stimulus. There is therefore ambiguity regarding what it is that the dot probe is actually measuring and thus, what cognitive mechanisms are being investigated via its use. Hence, while it is a more direct method of examining attention than the Stroop or dual-task paradigms, it is still not wholly appropriate for examining and measuring attentional bias and investigating the cognitive mechanisms of attentional bias meaning that a more direct measurement is required.

Given that visual attention is very closely related to visual awareness (Lamme, 2003), one paradigm that was created in order to be a 'purer' or more direct way of studying attentional bias – with the saliency of bias-related stimuli as primary focus – is the flicker paradigm that induces change blindness (Rensink, O'Regan, & Clark, 1997). Change blindness is a phenomenon relating to the

inability of the visual system to detect changes to the visual world if vision is somehow interrupted. This interruption can come from many sources, including during the period of saccadic suppression when the eyes move, attention being allocated to different regions, when a scene is of only marginal interest or when the sudden onset/offset of a probe/change is masked by a competing transient (Rensink et al., 1997). The latter is the basis of the flicker paradigm, in which two slightly different static images are presented to viewers, who are required to detect the change (Simons & Levin, 1997). If the two images are shown sequentially, the changes are easy to detect (Simons & Ambinder, 2005). However, with a mask interspersing the images, the change can be so difficult to detect it can take many alternations of the images to be detected (Rensink et al., 1997).

There has been some debate on the precise nature of change blindness. Some researchers have argued that we are blind to visual items we do not attend do, coining the term 'inattentional blindness' (Mack, 2003; Mack & Rock, 1998), whereas others have proposed that we do 'see' all items in our visual field, but immediately forget those we do not attend to – inattentional amnesia (Wolfe, 1999). While subsequent research favours the theory of inattentional blindness (Rees, Russell, Frith, & Driver, 1999), the fact that both standpoints stress the importance of attention is crucial and suggests that paradigms utilising change blindness may be more direct measures of the allocation of visual attention than the use of Stroop, dual-task or dot-probe paradigms. It therefore follows that paradigms utilising change blindness may be more direct measures of attentional bias and the cognitive mechanisms of attentional bias; the flicker task being a prime example.

Currently, there exist two versions of the flicker task; alternating images and one-shot paradigms. To date, only the former has been used to investigate attentional bias. Here, two virtually identical visual scenes, usually with a pathology-related change between them, are sequentially displayed to participants. However a mask is presented in between, inducing change blindness. The images and mask alternate until a participant accurately detects the change. This version of the flicker task calculates change detection latency, or the time it takes participants to detect the change. The faster

the change detection latency, the more severe the attentional bias is argued to be since this displays a faster allocation of attention towards pathology-related items. Studies that have used this version of the task are wide-ranging. It has been found that individuals with sleep disorders such as insomnia show an attentional bias towards sleep-related items (Jones et al., 2005). Another study discovered that cannabis users exhibit an attentional bias towards smoking and drug related items (Jones, Jones, Blundell, & Bruce, 2002). Heroin addicts have been found to display an attentional bias towards drug paraphernalia (Bearre et al., 2007). Findings are also consistent with investigations into smoking, where smokers have been observed to display an attentional bias towards smoking-related objects such as lighters and cigarettes (Yaxley & Zwaan, 2005). Finally, not only has it been found that that alcoholics and problem drinkers have an attentional bias towards alcohol-related items, but that these changes are detected at the cost of neutral changes also present (Jones et al., 2006; Jones, Jones, Smith, & Copley, 2003). However, there are issues surrounding potential confounds with the alternating-image flicker task that cannot be controlled for such as participants adopting various systematic search strategies (e.g. starting at the top-left of an image and gradually moving towards the bottom-right as if reading a page in a book).

Alternatively, the one-shot paradigm is known to be highly sensitive to changes in the allocation of attention (Scholl, 2000; Smith & Schenk, 2008, 2010). Due to the usefulness of the one-shot change detection paradigm in assessing attentional allocation, it has been used in conjunction with cognitive neuroscience techniques such as fMRI and TMS (Beck, Muggleton, Walsh, & Lavie, 2006; Beck, Rees, Frith, & Lavie, 2001). Here, there is only one alternation between two images, and a change either may or may not exist. Participants are asked to indicate if they believe there was a change between the images or not. In this variation of the flicker paradigm, both accuracy and reaction times are measured. A lower accuracy is indicative of increased change blindness, which is indicative of attention being allocated elsewhere. Similarly, higher accuracy is indicative of visual attention being captured by the changed stimulus.

The main advantage of the one-shot change detection paradigm over alternatives is that it can provide data on the initial allocation of attention or early attentional capture because participants have only the one chance at detecting a change or not. This allows researchers to calculate early visual sensitivity to detect changes to particular stimuli, allowing investigations not only into attentional capture by bias-related items, but also the potential distractibility of bias-related stimuli from detecting changes elsewhere. However despite its advantages, the one-shot change detection task has never been used to investigate attentional bias – only change blindness and visual awareness. Nevertheless, due to the findings from cognitive neuroscience studies that have used this paradigm alongside more restrained and conservative techniques such as TMS and have yielded valuable findings relating to visual attention and awareness (Beck et al., 2006; Beck et al., 2001) this paradigm appears to offer an appropriate avenue to answer questions relating to visual biases of attention.

1.6 Overcoming Current Issues

Currently there is therefore a need to overcome both the issues surrounding the use of inappropriate testing populations and the inconsistent and often flawed methodologies that have been employed in the study of attentional bias. One way to address the first of these issues would be to induce an attentional bias in a non-clinical population, and then compare findings to participants from the same population who have had no attentional bias induced. This would be an ideal way to probe the cognitive mechanisms underlying attentional bias, since all participants would be free from additional confounds such as the emotional saliency and reward associated with bias-related stimuli. Such an approach has been attempted, however even these have issues, placing uncertainty on findings. Yaxely and Zwaan (2005) investigated the development of a smoking-related attentional bias in both a clinical sample of smokers and a non-clinical sample of non-smokers. They separated smokers and non-smokers into two groups; one given information that the study was investigating smoking, and one naïve to this. Participants then completed a flicker task (Yaxley & Zwaan, 2005). Informed non-smokers detected the smoking-related change as fast as both informed

and naïve smokers. Thus, informed non-smokers and both informed and naïve smokers displayed a smoking-related attentional bias. The only group that showed no evidence of a smoking-related attentional bias was the group of naïve non-smokers.

These findings suggest not only that the clinical sample of smokers held a smoking-related attentional bias, but that the behavioural effect of this was at ceiling before the study information was provided (Cronbach, 1988). It also suggests that non-smokers can have an attentional bias induced via information provided before the commencement of testing. However, while this study highlights that information is sufficient to induce a bias-like effect in a healthy sample, the study was more social than experimental. There were no strict controls placed on the stimuli, for example they were not matched for size, contrast or luminance, and it is possible that some of the non-smokers who were provided with study-related information had relatives who smoked and were therefore more susceptible to developing a smoking-related attentional bias. Moreover, smoking-related stimuli are not arbitrary and therefore can trigger an emotional response (Janes et al., 2010). To investigate the possibility of inducing attentional bias further, the general idea of Yaxely and Zwaan's study should be examined in a more tightly monitored laboratory setting alongside an arbitrary stimulus to add control and remove any potential social/emotional confounds. This will offer a more precise avenue for the investigation of the cognitive aspects of attentional bias.

An alternative study examined the link between learned associations and the development of an attentional bias. Unlike Yaxely and Zwaan's study however, a healthy sample of university students was used allowing researchers to make direct comparisons between subject groups. Pischek-Simpson et al. (2009) split a group of university students into two equal groups. One group viewed neutral and angry faces; however some of the angry faces were paired with a small electric shock resulting in fear conditioning to induce an attentional bias towards angry faces. The other group viewed the same images with no accompanying shock. Both groups then completed a dot probe task to assess if the electric shock caused an attentional bias to develop towards angry faces. The group

who received a shock displayed evidence of an induced attentional bias however, the attentional bias did not generalise to the angry faces that were not originally accompanied by a shock (Pischek-Simpson et al., 2009). This study therefore suggests that it is possible to induce an attentional bias in a normative population. However firstly, due to the use of emotive stimuli (angry faces) there is still an issue with additional neural processing contributing to the inducement of the bias. Furthermore, when participants received the dot-probe task, the electrodes that delivered the shocks were still attached, meaning there was therefore a real chance that an additional shock could be delivered. This would further add to the additional emotional processing, meaning that the cognitive mechanisms of attentional bias were not directly investigated.

Pothos and Tapper (2010) did attempt to remove emotional confounds from attentional bias by inducing a Stroop effect in a healthy sample towards meaningless words in order to investigate if the amount of automatic associations with a word or the strength of an association causes the Stroop interference effects. They tested university students across 5 consecutive days to relate single non-words to either one real word or several related real words. At the end of the training, participants received a Stroop task containing all words (real and fake), and found that the Stroop effect was more pronounced for the non-word relating to only one real word (Pothos & Tapper, 2010). Thus, the Stroop effect is observed more in terms of the strength of a connection, not the quantity of connections it has with other words. However as previously mentioned, the Stroop test is more of a measure of semantic interference, not attention. Moreover, since this training had to take at least a week to be observed shows this suggests that the Stroop paradigm is not a sensitive measure of attention, which clouds the inferences that can be drawn from this study.

1.7 Thesis Aims

The aim for the thesis is therefore to examine attentional bias in a controlled laboratory setting using samples of healthy participants with an appropriate experimental paradigm that yields data on the initial allocation of attention. This will enable the investigation of the cognitive mechanisms of attentional bias, including how easy it is to manipulate the tipping point between the

representations of bottom-up and top-down information on the priority map that is believed to be the driving force behind biases of visual attention, and how robust these alterations may be. Carrying out these investigations will provide the first link between the large literature investigating pathological biases as a whole, and the more purely cognitive models of attention. These results can then be compared to a sub-clinical population, to discern what – if any – effects a pre-existing attentional bias has on future attentional allocation. The seemingly crucial links between attentional bias and the cognitive control of attention shall also be examined, with a focus on a potential causative role of the prefrontal cortex in the formation of attentional settings using tDCS. These investigations will provide a greater insight into the phenomenon of attentional bias and may have a wider-reaching impact upon a variety of conditions in which attentional biases are concurrent. By investigating the cognitive basis of attentional bias which is common to all populations, another mechanism which may be targeted for treatment could be uncovered.

Chapter 2

Developing a Suitable Paradigm to Investigate Attentional Bias

Overview

Current methodologies used to study attentional bias rely on inferences drawn from differential reaction times. However, these leave no way of knowing if attention was initially captured by bias-related information. This has resulted in unclear information regarding the boundary limits of when top-down information carries more weight than bottom-up information on the priority map. This chapter sought to develop an alternative methodology to investigate this. A one-shot change detection paradigm that has previously been used to study visual awareness was used, which provides reaction time and accuracy data. This allowed for independent calculations of perceptual sensitivity and responder bias, which provide an indication of initial attentional capture, and thus of attentional bias. The boundary limits of top-down and bottom-up information were examined yet further by removing all emotion from the task and inducing an attentional bias towards an arbitrary stimulus – the colour green – via an information sheet. Finally, an investigation of participant awareness was examined via the confidence of responses at the end of each trial. This task therefore determined if reading a single information sheet is sufficient to cause an alteration of the influence of top-down information on attentional capture, creating a situation where stimuli relating to the sheet capture and hold attention when all other stimulus-variables are controlled.

2.1 Introduction

Despite being widely studied, relatively little is known about the cognitive mechanisms underlying attentional bias, and how biases may initially develop. It is likely that attentional bias reflects the adoption of an attentional control setting that has skewed the impact of top-down compared to bottom-up information on the priority map (Bacon & Egeth, 1994; Leber & Egeth, 2006b); however this idea has never been directly studied. A key aspect of visual attentional bias is that attention is frequently and persistently *captured* by certain information more than it should ordinarily do so. Currently, all paradigms that investigate attentional bias yield reaction time data, however mechanisms driving the alterations are unknown. It is possible that alterations in reaction time may occur after attention has been disengaged from a non-bias-related stimulus. A paradigm that provides information on early attentional capture rather than solely reaction time data would therefore provide a more direct analysis of attentional bias. This would in turn allow for more concrete conclusions to be drawn about attentional bias since results unequivocally relate to the phenomenon, rather than behaviour being driven by additional processing.

One such paradigm is the one-shot change detection paradigm, outlined in the General Introduction on Pages 47-48 (Beck et al., 2006; Beck et al., 2001). Due to the make-up of the one-shot change detection paradigm over other existing methodologies, psychophysical analyses – specifically those relating to signal detection theory – can be applied to collected data allowing for the calculation of perceptual sensitivity and responder bias. This is because for any trial in which a change occurs, a Hit or Miss is recorded. Similarly, in any trial in which a change does not occur, a Correct Rejection or False Alarm is calculated. The resulting ratios of Hit/Miss/False Alarm/Correct Rejection responses allows for the calculation of d'; an independent measure of the ability of an individual to discern between variations of stimuli (Stanislaw & Todorov, 1999). In the case of the one-shot change detection paradigm, this is the ability of participants to discern between trials in which a change has occurred, and those in which no change has occurred.

A further advantage of using signal detection theory is that it allows for the calculation of Criterion or responder bias. This is crucial, since the ratio of responses (not measurements of perceptual sensitivity) is dependent not only on participants' perceptual sensitivity in different circumstances, but also on participants' own internal threshold of the point at which to decide if a change has occurred or not. Thus, participants can be conservative responders (more likely to respond that no change has occurred) or liberal responders (more likely to respond that a change has occurred). Conservative responders would therefore provide data with more Misses but fewer False Alarms, and liberal responders would provide the opposite. Criterion scores are independent of measurements of perceptual sensitivity, thus Criterion scores can change with d' scores staying the same and vice versa (Macmillan & Creelman, 2005). Consequently, the one-shot change detection paradigm provides an opportunity to obtain a variety of measurements relating to attention and attentional bias; including a measurement of the early allocation of attentional resources (since participants have only one opportunity with a limited time frame in which to view an array of stimuli before deciding if a change has occurred).

Such properties of the one-shot change detection paradigm make it the ideal choice for investigating biases of visual attention; however to date no such experiments have taken place. One aim of this chapter is therefore to probe the utility of using the one-shot change detection paradigm in the investigation of attentional bias. This novel approach shall also use a healthy, non-clinical sample alongside arbitrary, non-emotional stimuli (coloured circles with an attentional bias created towards the colour green) to fully remove behaviours relating to attentional bias from additional emotional or motivational processing. This will provide a clearer interpretation of findings with respect to the cognitive basis of attentional bias. Previous findings have also confounded by abnormal testing samples (as discussed in the general introduction). Thus, using a healthy, non-clinical sample will provide a clearer way to investigate the cognitive mechanisms of attentional bias.

As mentioned, a further confound that shall be addressed in this chapter is the impact that additional emotive processing has on the establishment of an attentional bias. Attentional bias most likely develops via the adoption of an attentional setting in order to satisfy a behavioural goal (Bacon & Egeth, 1994; Folk & Remington, 1998; Folk et al., 1992; Leber & Egeth, 2006b). However, attentional bias is typically studied in abnormal settings (within addictive behaviours, anxiety etc), where there are strong emotional reactions to bias-related stimuli (Janes et al., 2010). This is the case even in attempts to study bias in non-clinical populations (Pischek-Simpson et al., 2009; Yaxley & Zwaan, 2005). Since associative learning (via fear conditioning and reward) is known to impact the allocation of visual attention (Anderson et al., 2011a, 2011b; Kiss et al., 2009), it also remains unknown if additional motivational or emotional responses are necessary to alter the attentional control settings and thus cause an attentional bias. Using arbitrary, highly controlled stimuli – such as circles of equal size and luminance differing only in their hue – will overcome this issue and will offer an avenue to examine the boundary limits of the point at which top-down information carries more weight on the priority map than bottom-up information.

The current study shall therefore aim to induce an attentional bias towards an arbitrary stimulus – the colour green – using only a single information sheet. The presence of an attentional control setting favouring the colour green shall be investigated using the one-shot change detection paradigm. This will allow for a discovery regarding the possibility of inducing an attentional bias towards an arbitrary stimulus, and secondly, if the one-shot change detection paradigm is sensitive enough to detect such induced attentional biases. It is predicted that the information sheet will create an attentional setting prioritising green items. This will cause participants to be more accurate, more sensitive and faster at detecting changes to green stimuli after reading the information sheet as their attentional setting will preferentially alter their position on the priority map, thus biasing attention towards the green stimuli. If attention is captured and held by green stimuli, participants should also be more confident with their responses towards green-change trials. As such, after answering whether they perceived a change, participants shall be asked to indicate if

they were confident with their response or not. In this case, it is predicted that participants will be more confident with their responses towards green change trials than towards other changes.

2.2 Method

The experiment comprised of two conditions – a bias condition where the experimental tasks were preceded by an information sheet about the nature of the study in order to induce an attentional bias, and a neutral condition where only a neutral information sheet was provided. As eye movements, attention and visual awareness have been found to be closely related (Theeuwes, Belopolsky, & Olivers, 2009) and visual awareness of a stimulus is much greater when the eyes are fixated on it than when it is presented in the periphery (Martinez-Conde, Macknik, & Hubel, 2004), eye movements were prevented. This acted as a control to eliminate possible confounds of eye movements and fixation on change detection. Participants were asked to remain fixated on a central cross at all times and were reminded of this requirement between each block of trials. Additionally, eye movements were detected via Electrooculography (EOG). Trials in which eye movements were made were removed from the analysis.

2.2.1 Participants

Participants were 20 undergraduate students (4 male) in their first or second year of an Applied Psychology programme at Durham University. Ages ranged from 18 to 38 (M: 20.7, median: 19, SD: 4.7). All participants had normal or corrected to normal vision and gave their informed consent with the approval of Durham University Ethics Advisory Committee. Participants were compensated for their time in the form of course credits.

2.2.2 Apparatus & Stimuli

There were two types of information sheet and consent form used in the experiment – one for each condition. For the Bias condition, the forms used the word ‘green’ several times. For the Neutral condition, this was substituted for ‘colour’. The sheets determined which condition of the experiment participants were assigned to, were written in size 14 Times New Roman text and printed in black ink on A4 white paper (see appendix A and B).

All experimental stimuli were programmed in C++ using Borland C++ builder and produced via a VSG ViSaGe box and custom graphics card (Cambridge Research Systems, Rochester, England). They were displayed using a 19“ Sony Triniton monitor with a resolution of 1024x768 and a refresh rate of 100Hz. Responses were collected via a custom-made two-button button box, recording accuracy and reaction time. EOG recordings followed the guidelines of Brown et al. (2006) and were taken using a Biopac System (BIOPAC Systems, Santa Barbara, California). Three electrodes; one at the outer canthi of each eye, and one on the forehead to act as a reference point were secured using micropore tape. Recordings were triggered at the beginning of each trial, with an acquisition sampling rate of 200 samples per second. Recordings were passed through a low pass filter to reduce noise from the amplifier via Acq*Knowledge* software.

A white fixation cross situated in the centre of a black screen (0.7 x 0.7° visual angle) preceded the test array consisting of a circular (10.2 x 10.2° visual angle) composition of six circles (2.5° x 2.5° visual angle) each of which was one of eight different equiluminescent colours (green, red, blue, pink, purple, grey, mustard or orange, all 34 cd/m^2). The mask was a black screen.

2.2.3 Design

Participants were assigned to one of two groups. All participants completed both the Neutral and Bias tasks, which were separated by a one-week interval; however the order in which they completed the tasks was split. 50% of participants completed the Bias task in Week One and the Neutral task in Week Two; 50% completed the tasks in the opposite order. The experiment therefore had a mixed design. There was a within subjects factor of Bias (Bias v Neutral) and a between subjects factors of Order (Neutral then Bias vs Bias then Neutral).

2.2.4 Procedure

Participants were asked to read through an instruction sheet detailing the task they had to carry out. The Bias sheet used the word “green” six times to induce an attentional bias towards green stimuli; the Neutral used the word “colour”. After reading the information and instruction sheets, the lights were switched off to ensure that testing took place in a darkened room with the only light source

coming from the monitor. Participants were then seated centrally 57cm away from the screen with their head in a chin rest, which was height adjustable to ensure central fixation. Participants were presented with the one-shot change-detection task, where they were informed that their goal was to detect any changes between two sequentially presented arrays that were separated by a mask. A change was defined as one coloured stimuli changing into a different colour not already present in the array. Participants were advised that if a change was present, it would only occur to one stimulus at a time, and could occur to any stimulus in any location in the array.

A fixation cross appeared for 1000ms, followed by the stimulus array for 1500ms. The array was then masked for 100ms before reappearing. Stimuli remained present until a response was made. Participants were required to respond as quickly but as accurately as possible via a two-button button box whether they believed a change had occurred (right press) or not (left press). Answers were made using the index finger of each hand. On 25% of trials (45 trials) a green item was present and changed colour (Congruent Change Trials), on 25% of trials a green item was present but a different item changed colour (Incongruent Change Trials), on 25% of trials no green item was present and an item changed colour (Neutral Change Trials) and on 25% of trials a green item was present but no change occurred (No Change Trials). The position of the coloured items was varied randomly across trials. At the end of each trial, participants were then asked to indicate via the button box if they were confident with their response (right press) or not (left press). Following their response to the confidence question, a blank screen was presented for 500ms (inter-trial interval) before the next trial began. See Figure 1 for the procedure of a typical trial (figure shows a Congruent Change trial). Participants completed 3 blocks of 60 trials with a 5 minute break between each block.

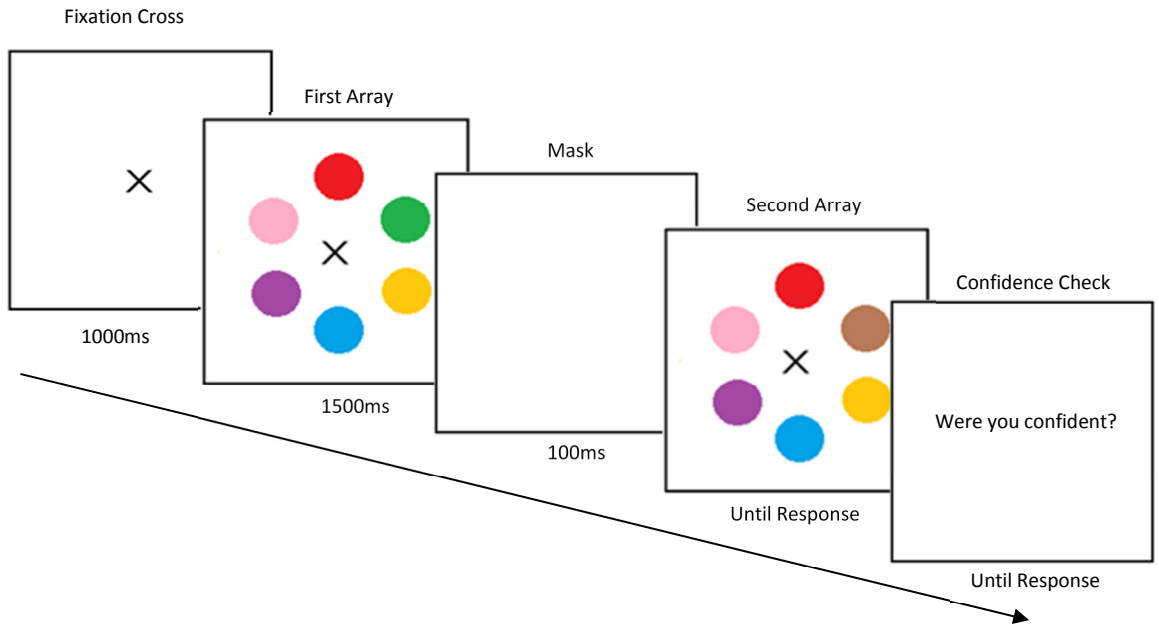

Figure 2.1: **Procedure of a typical trial**. A fixation cross is shown for 1000ms followed by the first experimental array for 1500ms. This is then masked by a blank screen for 100ms before reappearing until a participant has made a response. Once a response has been made, participants are asked if they were confident with their chosen response.

2.3 Results

Outliers with a reaction time above or below 2 standard deviations from the mean were excluded from analyses, resulting in the loss of 2.44% of trials. Additionally, trials in which an eye-movement was made away from the central fixation cross were excluded. This resulted in the loss of an additional 0.58% of trials, suggesting that reminding participants to remain fixated on the central cross in between each block of trials was a successful strategy for maintaining fixation.

2.3.1 Reaction Time

Mean reaction time of participants was entered into a 2 (Order: Neutral then Bias/Bias then Neutral) x 2 (Bias: Neutral/Bias) x 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) Mixed Factor ANOVA. Bias and Trial were within subjects factors, Order was a between subjects factor.

There was a Main Effect of Trial: $F(2, 36) = 13.686$, $p < .001$. Pairwise comparisons following a Bonferroni correction revealed that reaction times of Congruent Change trials compared to

Incongruent Change trials were faster by an average of 94.48ms (p = .004, r = .664). Additionally, reaction times of Congruent Change trials compared to Neutral Change trials were faster by an average of 82.96 (p = .003, r = .682). Reaction times of Incongruent compared to Neutral Change trials did not differ.

There was also an interaction between Bias and Order: F(1, 18) = 21.196, p <.001. This was further investigated via two paired samples t-tests. One compared reaction times of Bias compared to Neutral conditions for the Neutral then Bias group, and one compared the same for the Bias then Neutral group. The t-test for the Neutral then Bias group was significant: t(29) = 4.017, p <.001, r = .598. Reaction times in the Neutral condition were significantly slower (M: 838.24ms) than reaction times in the Bias condition (M: 721.56ms). The t-test for the Bias then Neutral group was also significant: t(29) = -3.130, p = .004, r = .524. However here, reaction times in the Neutral condition were significantly faster: (M: 806.44ms) than reaction times in the Bias condition (M: 881.03ms).

Finally, there was an interaction between Bias and Trial: F(2, 36) = 4.529, p .018. To elucidate, two repeated measures ANOVAs were conducted. One examined participants' reaction times across Trials for the Neutral condition, and the other examined the same for the Bias condition (see Fig. 2). The ANOVA for the Neutral condition was non-significant: F(2, 38) = 2.623, p = .086. However, the ANOVA for the Bias condition was significant: F(2, 38) = 11.154, p<.001. Pairwise comparisons revealed that participants were significantly faster in Congruent Change trials compared to Incongruent Change trials by an average of 149.693ms (p = .008, r = .623). Congruent Change trials were also detected significantly faster than Neutral Change trials by an average of 133.554ms (p = .006, r = .636). There was no difference in reaction times between Incongruent and Neutral Change trials.

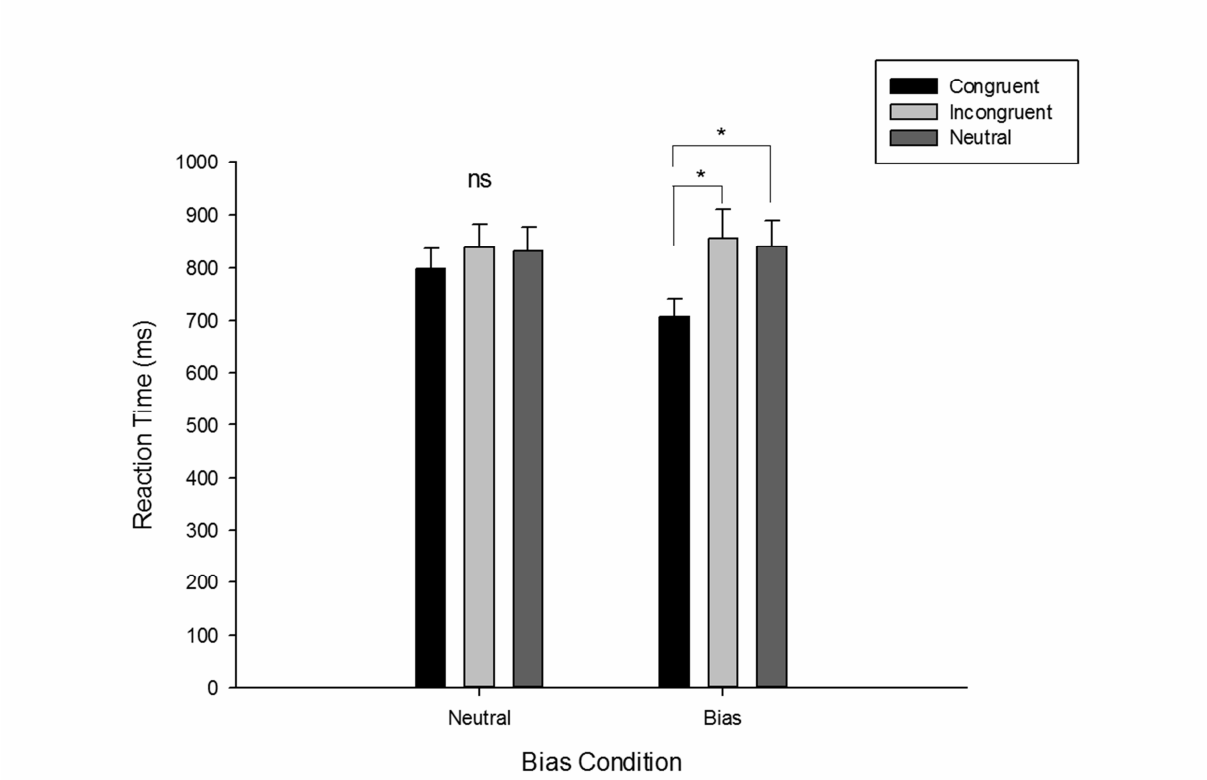

Figure 2.2: **Effect of induced attentional bias on reaction time:** interaction between Bias (Neutral/Bias) and Type of Trial (Congruent/Incongruent/Neutral). Reaction times in the Neutral condition did not differ. However, in the bias condition, reaction times for Congruent change trials were significantly faster than those for Incongruent or Neutral change trials. Note: * p<.05

2.3.1.1 Interim Discussion

The interaction between Bias and Order is indicative of overall practice effects. Since the Neutral then Bias group all completed the Bias task in their second session and the Bias then Neutral group all completed the Neutral task in their second session, participants had already completed one session of the change detection task, and were all therefore faster in their second session than their first session.

2.3.2 Accuracy

Mean accuracy, calculated as the proportion of correct trials was also entered into a 2 (Order: Neutral then Bias/Bias then Neutral) x 2 (Bias: Neutral/Bias) x 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) Mixed Factor ANOVA. As before, Bias and Trial were within subjects factors, Order was a between subjects factor.

There was a Main Effect of Trial: $F(2, 36) = 26.565$, $p<.001$. Congruent Change trials were detected significantly more accurately than Incongruent Change trials by an average of .135 ($p <.001$, $r = .870$), and Neutral Change trials by an average of .111 ($p <.001$, $r = .751$). There was no difference in accuracy between Incongruent and Neutral Change trials. There was also a significant interaction between Bias and Order: $F(1, 18) = 12.931$, $p = .002$. This was investigated via two paired samples t-tests. One compared accuracy of Bias compared to Neutral conditions for the Neutral then Bias group, and one compared the same for the Bias then Neutral group. The t-test for the Neutral then Bias group was non-significant: $t(29) = -1.643$, $p = .111$. However, the t-test for the Bias then Neutral group was significant: $t(29) = 2.846$, $p = .008$. Here, accuracy in the Neutral condition was significantly higher (M: .7918) than accuracy in the Bias condition (M: .7370).

Finally, there was a significant interaction between Bias and Trial $F(2, 36) = 22.172$, $p <.001$. This was further examined via two repeated measure ANOVAs (see Fig 2.3). One examined Trial in the Neutral condition, and the other examined the same for the Bias condition. The ANOVA for the Neutral condition was non-significant: $F(2, 38) = 2.861$, $p = .070$. However, the ANOVA for the Bias condition was significant: $F(2, 38) = 40.583$, $p<.001$. Participants were significantly more accurate in Congruent compared to Incongruent trials by an average of .220 ($p <.001$, $r = .896$), and Congruent compared to Neutral trials by an average of .187 ($p <.001$, $r = .835$). Accuracy between Incongruent and Neutral trials did not differ ($p = .623$).

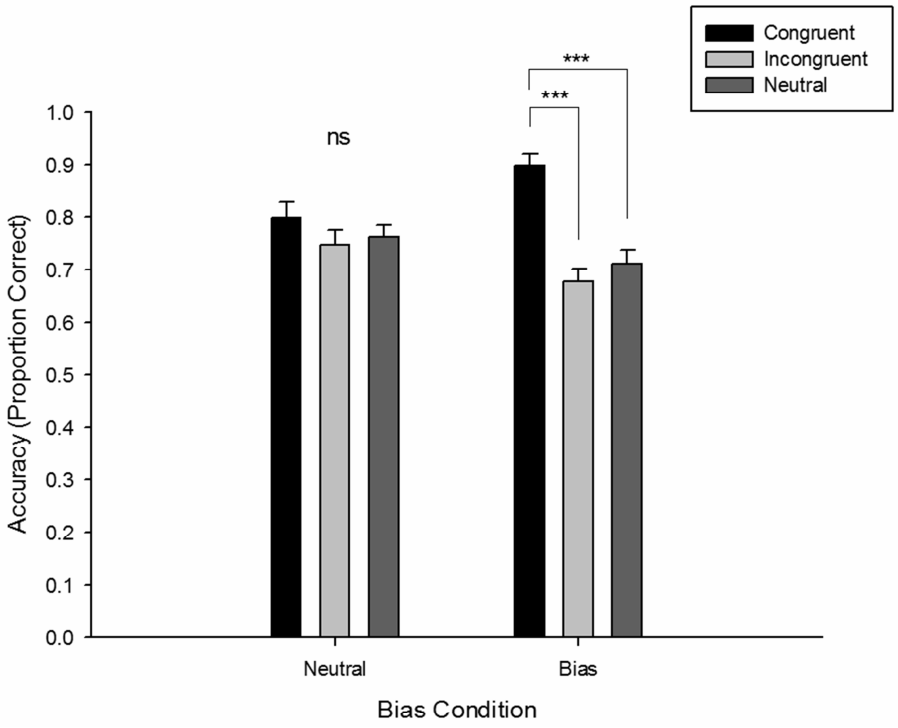

Figure 2.3: **Effect of induced attentional bias on accuracy:** interaction between Bias (Neutral/Bias) and Type of Trial (Congruent/Incongruent/Neutral). Accuracy between various trials in the Neutral condition did not differ. In the bias condition, accuracy for Congruent change trials was significantly higher than those for Incongruent or Neutral change trials. Note: *** p<.001

2.3.2.1 Interim Discussion

It is possible that the Bias x Order interaction results reflect a mixture of the Bias effect along with generalised practice effects. For the Bias then Neutral group, the biasing quality of the green stimulus lowered accuracy when it is either not present (since there is only a 1-in-6 chance of attending to the changed stimulus) or is present and does not change (since attention is captured here by the green stimulus that does not change), resulting in overall reduced accuracy in the Bias condition. This effect is still present, but not as extreme when this group performs the Neutral condition. However, participants in the Neutral then Bias group first receive practice at the task free from bias-related distractions before completing the Bias task, where these initial bias-free practice effects could have been utilised.

2.3.3 Sensitivity (d')

Sensitivity to detect changes between arrays was calculated. This was measured as d', where a higher d' is indicative of greater sensitivity at detecting changes, and was entered into a 2 (Order: Neutral then Bias/Bias then Neutral) x 2 (Bias: Neutral/Bias) x 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) Mixed Factor ANOVA. Bias and Trial were within subjects factors, Order was a between subjects factor.

There was a main effect of Bias: $F(1,18) = 17.763$, $p = .001$, $r = .705$. Sensitivity in the Bias condition was greater (M: 3.342) than sensitivity in the neutral condition (M: 2.295). There was also a main effect of Trial: $F(2,36) = 10.107$, $p < .001$. Sensitivity at detecting Congruent Change trials was higher than Incongruent Change trials by an average of .750 ($p < .001$, $r = .763$), and higher than Neutral Change trials by an average of .997 ($p = .004$, $r = .724$). There was no difference in sensitivity of Incongruent and Neutral Change trials. Bias and Trial interacted: $F(2, 36) = 33.965$, $p < .001$. To clarify, two repeated measure ANOVAs were conducted. One examined d' scores for Trial in the Neutral condition, and the other examined the same in the Bias condition. The ANOVA for the Neutral condition was non-significant: $F(2,38) = 2.966$, $p = .095$. However, the ANOVA for the Bias condition was significant: $F(2, 38) = 27.523$, $P < .001$. Here, participants were significantly more sensitive at detecting Congruent than Incongruent Change trials by an average of 1.293 ($p < .001$, $r = .759$), and Congruent than Neutral Change trials by an average of 2.393 ($p < .001$, $r = .811$). Finally, participants were significantly more sensitive at detecting Incongruent than Neutral Change trials by an average of 1.1 ($p = .002$, $r = .639$).

Additionally, there was a significant three-way interaction between Bias, Trial and Order: $F(2, 36) = 3.285$, $p = .049$. To clarify, the interaction between Bias and Trial was examined separately for the two types of Order (Neutral then Bias and Bias then Neutral) via two 2 (Bias: Neutral/Bias) x 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) Within Factor ANOVAs.

For the Neutral then Bias ANOVA, there was a main effect of Bias: $F(1, 9) = 10.992$, $p = .009$. Participants were significantly more sensitive at detecting changes in the Bias condition (M: 3.094) than the Neutral condition (M: 2.041, $r = .741$). This could be explained by simple practice effects, since all participants in this analysis received the Neutral condition first, followed the Bias condition. There was also a main effect of Trial: $F(2, 18) = 10.107$, $p < .001$. Participants were significantly more sensitive at detecting Congruent than Incongruent Change trials by an average d' score of 0.6 ($p = .009$, $r = .745$), and more sensitive at Congruent than Neutral Change trials by an average d' score of 0.815 ($p = .036$, $r = .634$). There was no difference sensitivity between Incongruent and Neutral Change trials ($p = .489$).

Finally, there was an interaction between Bias and Trial: $F(2, 18) = 7.111$, $p = .005$. To clarify, two repeated measure ANOVAs were conducted. One examined Trial in the Neutral condition, and the other examined the same for the Bias condition (see Fig. 4). The ANOVA for the Neutral condition was non-significant: $F(2, 18) = .264$, $p = .771$. However, the ANOVA for the Bias condition was significant: $F(2, 18) = 10.407$, $p = .001$. Participants were more sensitive at detecting Congruent than Incongruent Change trials by an average d' score of 1.188 ($p < .001$, $r = .859$), and were more sensitive than Neutral Change trials by an average d' score of 1.856 ($p = .003$, $r = .809$). Again, there was no difference between Incongruent and Neutral Change trials ($p = .159$).

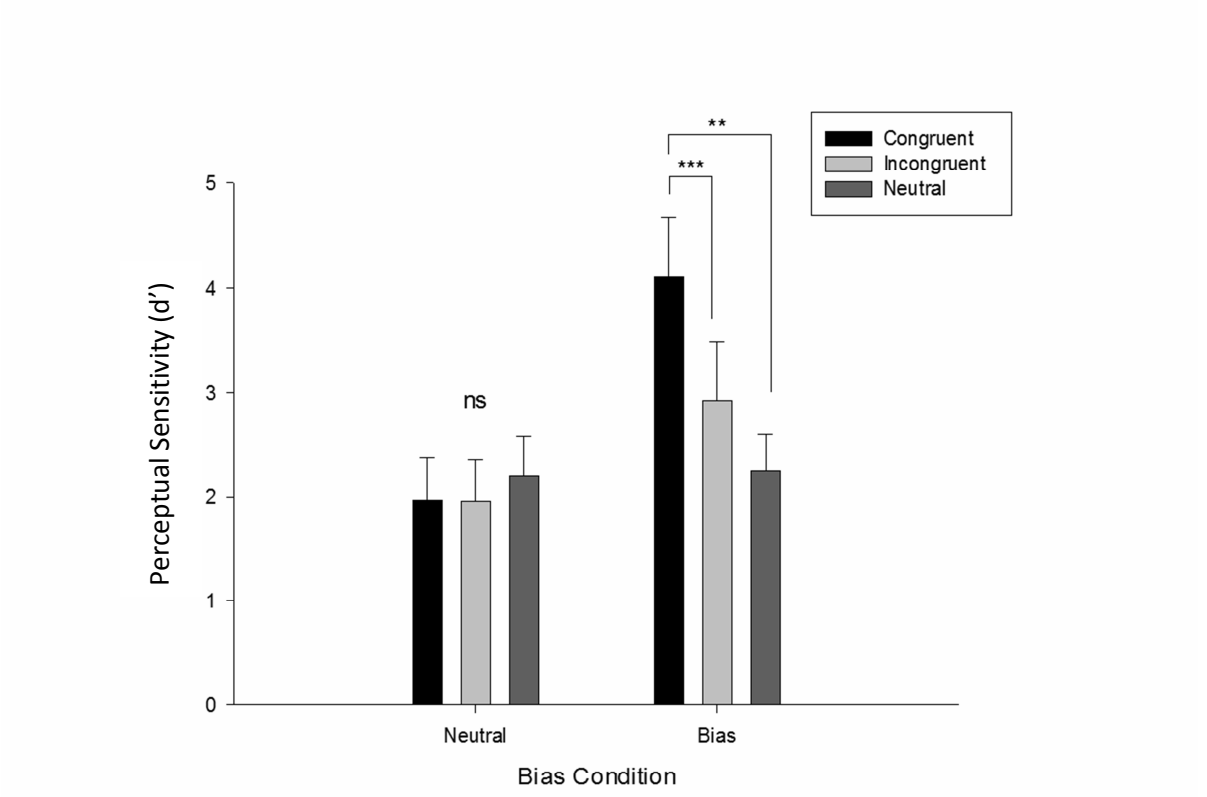

Figure 2.4: **Effect of induced attentional bias on perceptual sensitivity in the Neutral then Bias group:** interaction between Bias (Neutral/Bias) and Type of Trial (Congruent/Incongruent/Neutral). d' Scores between various trials in the Neutral condition did not differ. In the bias condition, d' scores for Congruent change trials was significantly higher than those for Incongruent or Neutral change trials. A higher d' signifies greater sensitivity to change. Note: ** p<.005, *** p<.001

For the Bias then Neutral ANOVA, there was a main effect of Bias: F(1, 9) = 7.421, p = .023. Participants were significantly more sensitive at detecting changes in the Bias condition (M: 3.590) than the Neutral condition (M: 2.550, r = .672). This finding cannot be due to practice effects, since all participants in this group received the Bias condition first. Thus, the fact that Congruent Change trials made up 25% of the total number of trials is driving this effect. There was also a main effect of Trial: F(2, 18) = 5.558, p = .013. Participants were significantly more sensitive at detecting Congruent than Incongruent Change trials by an average of 0.9 (p = .005, r = .780), and more sensitive at Congruent than Neutral Change trials by an average of 1.178 (p = .042, r = .620). There was no difference between Incongruent and Neutral Change trials (p = .410).

There was also a Bias x Trial interaction: F(2, 18) = 40.675, p <.001. Two repeated measure ANOVAs were conducted. One examined Trial in the Bias condition, and the other examined the same in the

Neutral condition (see Fig 2.5). As before, the ANOVA for the Bias condition was significant: $F(2, 18) = 18.323$, $p < .001$. Participants were more sensitive at detecting Congruent than Incongruent Change trials by an average of 1.398 ($p = .005$, $r = .767$), and more sensitive at Congruent than Neutral Change trials by an average of 2.103 ($p = .001$, $r = .842$). Additionally, participants were more sensitive at detecting Incongruent than Neutral Change trials by an average of 1.531 ($p = .004$, $r = .788$). However, unlike the Neutral then Bias group, the ANOVA for the Neutral condition was also significant: $F(2, 18) = 4.039$, $p = .036$. Here, participants were significantly more sensitive at detecting Congruent than Incongruent Change trials by an average of 0.401 ($p = .024$, $r = .671$). However, unlike with any other comparisons, participants were significantly more sensitive at accurately detecting Neutral than Incongruent Change trials by an average of 0.974 ($p = .023$, $r = .674$). There was no difference between the sensitivity of Congruent and Neutral Change trials ($p = .240$).

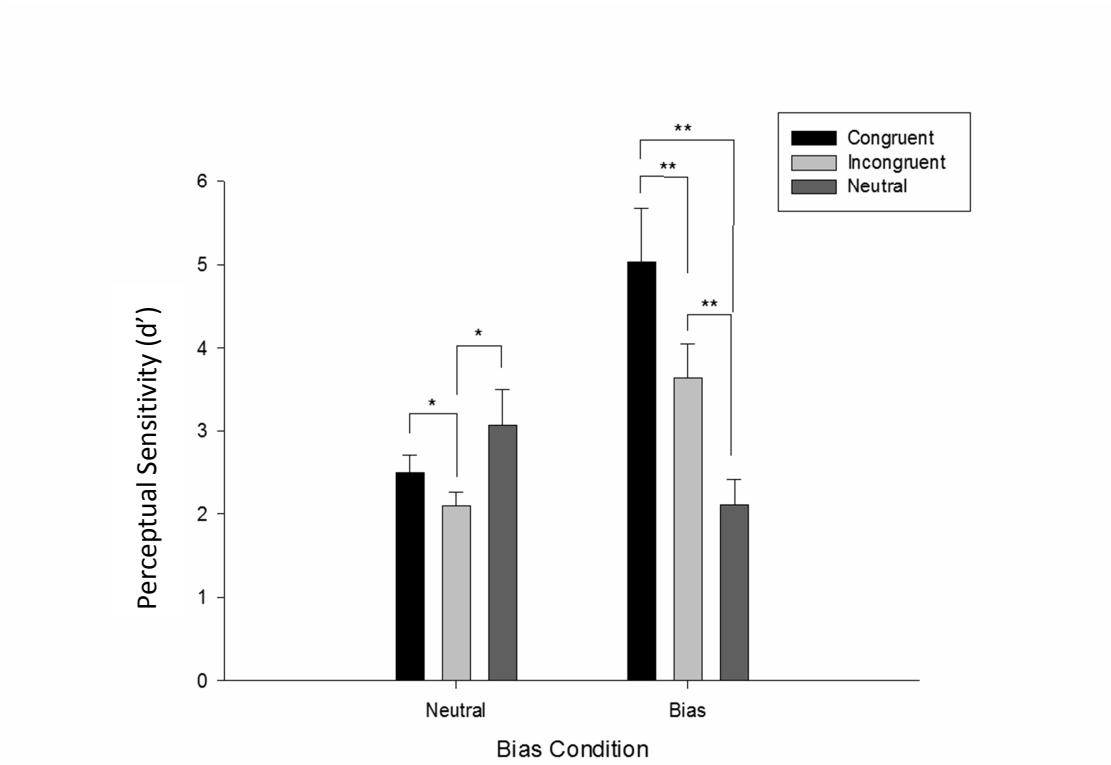

Figure 2.5: **Effect of induced attentional bias on perceptual sensitivity in the Bias then Neutral group:** interaction between Bias (Neutral/Bias) and Type of Trial (Congruent/Incongruent/Neutral). d' Scores for Congruent trials versus Incongruent trials in the Neutral condition were significantly higher. Neutral trials compared to Incongruent trials also had a higher d' score in the Neutral condition. In the bias condition, d' scores for Congruent change trials was significantly higher than those for Incongruent or Neutral change trials. However, d' scores for Incongruent trials were also significantly higher than Neutral trials. A higher d' signifies greater sensitivity to change. Note:
* p<.05, ** p<.005

2.3.4 Responder Bias (Criterion)

A measurement of participant responder bias was calculated. This was measured as a Criterion Score, where a higher Criterion is indicative of more conservative responding (more likely to report there being no-change between arrays). Criterion Scores were entered into a 2 (Order: Neutral then Bias/Bias then Neutral) x 2 (Bias: Neutral/Bias) x 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) Mixed Factor ANOVA. Bias and Trial were within subjects factors, Order was a between subjects factor.

There was a main effect of Bias $F(1, 18) = 11.044$, $p = .004$. Criterion Scores in the Neutral condition were significantly lower (M: 0.342) than the Bias condition (M: .759). There was also a main effect of Trial: $F(2, 36) = 4.978$, $p = .012$. Criterion Scores of Congruent Change trials were lower than Incongruent Change trials by an average of 0.353 ($p < .001$, $r = .866$). Criterion Scores of Congruent and Neutral Change or Incongruent and Neutral Change trials did not differ. Since a lower Criterion is indicative of more liberal responding, this suggests that participants were more liberal with their responses towards Congruent than Incongruent Change trials.

Bias and Trial interacted: $F(2, 36) = 13.940$, $p < .001$. This was examined by two repeated measures ANOVAs – one examined Criterion for Trial in the Neutral condition, the other did the same in the Bias condition (see fig. 2.6). The ANOVA for the Neutral condition was significant: $F(2, 18) = 4.994$, $p = .012$. Criterion Scores for Congruent Change trials were significantly lower than Incongruent Change trials by an average of 0.106 ($p = .039$, $r = .453$). Criterion Scores for Congruent Change trials were also significantly lower Neutral Change trials by an average of 0.386 ($p = .019$, $r = .508$). There was no difference between Incongruent and Neutral Change trials.

The ANOVA for the Bias condition was also significant: $F(2, 18) = 10.433$, $p < .001$. Here, Criterion Scores of Congruent Change trials were significantly lower than Incongruent Change trials by an average of 0.601 ($p < .001$, $r = .753$). There was no difference between Congruent and Neutral trials ($p = .691$), however the Criterion of Neutral trials were significantly lower than Incongruent Change

trials by an average of 0.683 (p <.001, r = .708). Thus, it appears as if participants in the Bias condition were significantly more conservative with their responses when a green circle was present but did not change.

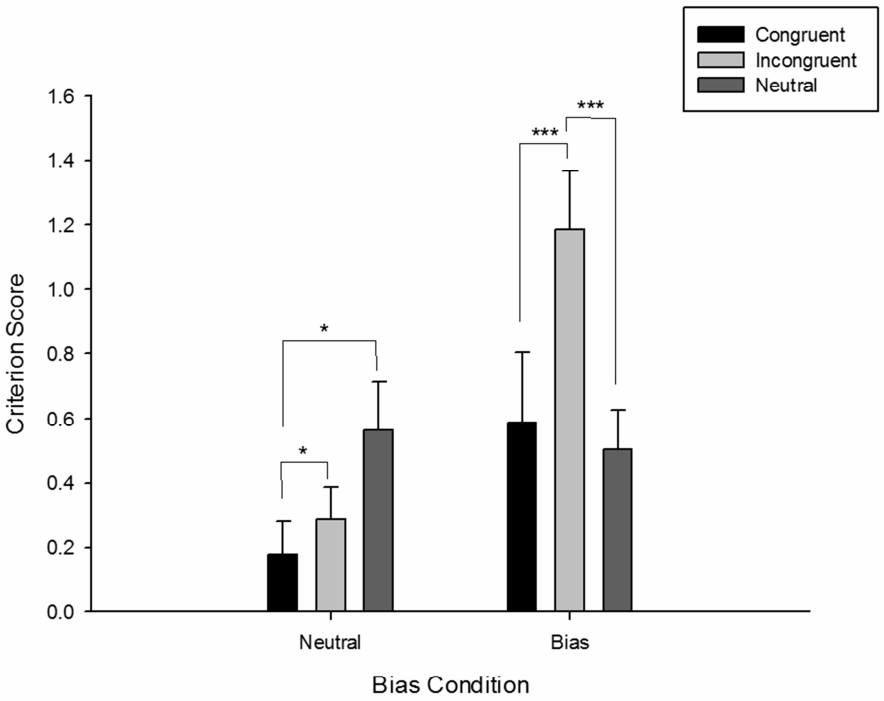

Figure 2.6: **Effect of induced attentional bias on Responder Bias:** interaction between Bias (Neutral/Bias) and Type of Trial (Congruent/Incongruent/Neutral). Criterion Scores for Congruent trials versus Incongruent trials in the Neutral condition were significantly lower. Criterion scores for Neutral Change trials in the Neutral condition were significantly higher than Incongruent Change trials. In the bias condition, Criterion scores for Congruent change trials was significantly lower than those for Incongruent change trials. However, Criterion scores for Incongruent trials were significantly higher than Neutral trials. A higher Criterion score more conservative responding – i.e., more likely to report No Changes than Changes. Note: * p<.05, *** p<.001

Confidence

This experiment also examined the confidence of participants' responses. At the end of each trial, participants reported that they were either confident or not confident with their response to the given trial.

2.3.5 Overall Confidence

The overall proportion of trials in which participants reported being confident was calculated and entered into a 2 (Order: Neutral then Bias/Bias then Neutral) x 2 (Bias: Neutral/Bias) x 3 (Trial:

Congruent Change/Incongruent Change/Neutral Change) Mixed Factor ANOVA. Bias and Trial were within subjects factors, Order was a between subjects factor. Here, there was a main effect of Trial: $F(2, 36) = 3.433$, $p = .043$. The only significant difference in the proportion of confident trials was between Congruent (M: .852) and Neutral (M: .796) trials, where participants reported being significantly more confident in responses towards Congruent Change trials by an average of .056 ($p = .048$, $r = .446$).

2.3.6 Confidence of Accurate Trials

Finally, the proportion of confident trials was calculated for correct change detections only. These were entered into a 2 (Order: Neutral then Bias/Bias then Neutral) x 2 (Bias: Neutral/Bias) x 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) Mixed Factor ANOVA. Again, Bias and Trial were within subjects factors, Order was a between subjects factor. As with the previous Confidence analysis, there was a main effect of Trial: $F(2, 36) = 13.171$, $p < .001$. For accurate trials, participants were significantly more confident with responses towards Congruent Change trials (M: .915) than Incongruent Change trials (M: .852) by an average of .063 ($p < .001$, $r = .744$). Likewise, participants were also more confident with their responses towards Congruent Change trials than Neutral Change trials (M: .848) by an average of .066 ($p = .001$, $r = .686$). Confidence did not differ between Incongruent and Neutral Change trials ($p = .813$).

Finally, Bias and Order interacted: $F(1, 18) = 4.735$, $p = .043$. This was investigated via two paired-samples t-tests. One examined confidence in the Bias compared to Neutral condition for the Neutral then Bias group. The other examined the same for the Bias then Neutral group. For the Neutral then Bias group, the overall proportion of confident responses for accurate trials in the Neutral condition was significantly lower (M: .834) than for the Bias condition (M: .876): $t(29) = -2.814$, $p = .009$, $r = .463$. There was no difference in Bias then Neutral group: $t(29) = 1.247$, $p = .222$, $r = .226$.

2.4 Discussion

The current study found that a single information sheet that mentions the colour green is sufficient to cause the adoption of an attentional control setting (Bacon & Egeth, 1994; Folk & Remington, 1998; Folk et al., 1992; Leber & Egeth, 2006b) favouring green items. This attentional control setting altered the weight carried by top-down representations on the priority map over bottom-up information, causing an increase in perceptual sensitivity and confidence in accurately detecting changes towards green items.

These findings are similar to those of Yaxely & Zwaan, who created a smoking-specific attentional control setting in a group of non-smokers (Yaxley & Zwaan, 2005). However, the current study makes some important advances to these original findings. Firstly, the study successfully induced an attentional bias towards a completely non-emotional and arbitrary stimulus, whereas Yaxely and Zwaan used a stimulus category with many emotional connotations attached to it. As such, while Yaxely and Zwaan were unable to control for potential strong emotional inferences many individuals draw towards smoking paraphernalia or potential personal or family histories surrounding smoking, the present findings were able to control for such potential confounds by using an arbitrary colour that has no emotional attachments. Furthermore, the current finding appeared to have an equal impact in all participant groups. This suggests that there is no prerequisite of emotion or emotional memories for an attentional bias to form and as such, the boundary limit of the point at which top-down information carries more weight than bottom-up information on the priority map does not require an emotional response. Furthermore, this findings offers support that the adoption of a top-down modulated attentional control setting which causes information relating to that setting to achieve higher peaks on the priority map is a cognitive basis of attentional bias that may be present across all populations who display evidence of the phenomena.

This raises important issues within the classic attentional bias literature, where strong emotional attachments (Baker, Morse, & Sherman, 1987; Dresler et al., 2012; Ryan, 2002), associative learning (Berridge & Robinson, 2003; Di Ciano & Everitt, 2004; Everitt, Dickinson, & Robbins, 2001; Field,

Munafo, & Franken, 2009; Ghitza, Fabbricatore, Prokopenko, Pawlak, & West, 2003; Robinson & Berridge, 2004; See, 2002; Weiss, 2005) or habitual dopaminergic reward pathways (Franken et al., 2005; Franken, Hendriks, Stam, & Van den Brink, 2004; Goldstein, Tomasi, et al., 2009; Kenny, Koob, & Markou, 2003; Li & Sinha, 2008; Vollstadt-Klein et al., 2012) are commonly attributed to the development and sustainability of attentional biases. The fact that a bias can form independent of such attributions suggests that attentional bias and the alteration of attentional control settings may form independently of emotion or reward, and then be subsequently reinforced by establishing new neural pathways via additional top-down mechanisms such as reward associations (Robinson & Berridge, 1993, 2000, 2008).

Furthermore, the current experiment was able to factor in controls that were not present in Yaxely and Zwaan (2005). These include ensuring all stimuli were of equal visual angle and luminance, ensuring all participants viewed the same experimental paradigms for the same length of time before making a decision. Unlike Yaxely and Zwaan's participants, participants in the current experiment were from the same cohort and were at a comparable level of education as each other. This also enabled the examination of the potential persistence of an induced attentional bias by inviting participants back after one-week to re-assess their visual biases towards green stimuli and thus probe the sustainability of the attentional control setting that was established by the initial information sheet in the first week of testing. Thus, while Yaxely and Zwaan (2005) provided valuable insights into the ease of inducing an attentional bias, the current study advanced upon these findings, offering a new and innovative method of investigating attentional bias that has developed our understanding of the phenomenon. Moreover, since the current study utilised the one-shot change detection paradigm, information regarding perceptual sensitivity rather than just reaction times were collected. Since in attentional bias, bias-related information has an effect on initial attentional capture (i.e. attentional bias operates early in perceptual processing), the additional data on perceptual sensitivity demonstrates that the information sheet did induce an

attentional bias, and does not simply reflect additional processing that occurs only after attention is allocated towards bias-related stimuli.

The findings from the current experiment were also able to probe the potential link between the formation of an attentional bias and learned behaviours such as conditioning (Pischek-Simpson et al., 2009). Pischek-Simpson et al. (2009) carried out an experiment with some controls over that of Yaxely and Zwaan by using a university sample. They found they were only able to induce an attentional bias towards negative faces via a physical negative association (an electric shock), however the attentional bias did not generalise to other angry faces that were not initially paired with an electric shock. These data also raise the possibility that an attentional control setting favouring a particular stimulus category can only be induced when additional processing (conditioned fear responses) occurs alongside, and therefore that the boundary of when top-down information carries a greater impact than bottom-up information on the priority map also requires this additional processing. Using the one-shot change detection paradigm, we were able to observe biases of visual attention towards all green stimuli (i.e., the bias was not restricted to a green stimulus in one specific location in the visual array) with no additional conditioning – either positive or negative – involved. The discrepancy between the current findings and previous studies may be because a bias was implicitly induced and then assessed via the dot probe paradigm in Pischek-Simpson et al.'s study, whereas the current study provided a more explicit information sheet to participants. Alternatively, it is possible that the dot probe paradigm is not as sensitive a measure of the locus of visual attention, further advocating the one-shot change detection task as the optimum paradigm to investigate initial biases of visual attention. Nevertheless, findings from the present experiment demonstrate the ease of altering the impact of top-down information via attentional control settings and show that it is relatively easy to induce an attentional bias. There is no need for additional emotional processing – such as occurs in conditioning – or the expectation of reward.

The one-shot change detection paradigm also has an advantage over the Stroop-type methodology previously employed (Pothos & Tapper, 2010). Pothos and Tapper were able to overcome issues surrounding emotion by using a variety of non-words in the creation of a Stroop effect; however participants in their study had to be trained daily for a full week before displaying the effect. The alteration in perceptual sensitivity observed in the current study suggests that the one-shot change detection paradigm is sensitive enough to detect subtle alterations of the prioritising of visual information. Moreover, it supports the arguments in Chapter 1 that previous clinical explorations of attentional bias using the modified Stroop paradigm are not detecting or measuring attentional biases, but reflect additional processing that occurs after the effects of an attentional bias. As noted by Yiend (2010) in a review of methodologies to investigate emotion and attention, there is "inherent ambiguity of the inferences that can be made from Stroop interference" (p. 18) – ambiguity that distracts from knowledge gathered on attentional bias using this paradigm. The present findings also suggest that through explicit means (an information sheet), attentional control settings can significantly alter how humans view the world around them. Since perceptual sensitivity was altered, this suggests that in attentional biases, individuals are not simply faster at reacting to bias-related stimuli when present but that they have an increased acute awareness of these items.

Given the similarity between the current findings, and cognitive explorations of the impact of top-down information on the priority map (Bacon & Egeth, 1994; Fecteau & Munoz, 2006; Folk & Remington, 1998; Folk et al., 1992; Kawahara, 2010; Leber & Egeth, 2006a, 2006b), it also seems more likely that the findings in this chapter refer to alterations to attentional control settings, rather than an alternative explanation of response inhibition which is more traditionally assessed via Go/No Go or Stop-Signal tasks (Boggio et al., 2007; Boucher, Palmeri, Logan, & Schall, 2007; Hsu et al., 2011; Logan, 1994; Murphy et al., 1999; Schachar, Tannock, & Logan, 1993; Verbruggen & Logan, 2008). Response inhibition refers to abilities to exercise high-level inhibitory control over responses in order to suppress unwanted responses. It is especially relevant to addiction, where it has been routinely found that addicted individuals have deficits in response inhibition (Fillmore & Rush, 2002;

Monterosso, Aron, Cordova, Xu, & London, 2005). In the current experiments, it is possible that the induced attentional bias affected the ability of participants to inhibit their responses towards green stimuli, such that when a green change was present, this resulted in a response. However, the one-shot change-detection paradigm showed that the information sheet used in the current experiment altered perceptual sensitivity of green items, suggesting that it wasn't simply the case that responses towards green items were less inhibited, but that the internal representation of green items was altered.

Despite the merits of the one-shot change detection paradigm, one observed result raises some concerns over its current format. Sensitivity to detect changes in the Bias condition was higher for trials where a green item was present but an alternative item changed colour (Incongruent trials) compared to trials in which no green item was present (Neutral trials). If attention was captured and held by green stimuli – as suggested by increased perceptual sensitivity of green items – this suggests that participants should be significantly less sensitive at detecting changes in Incongruent trials over Neutral trials. It is possible that the addition of the confidence question following each trial recruited additional neural processing; altering what is being examined via the paradigm in its current form. In other words, applying an additional criterion to the task may have engaged additional processes resulting in a task that no longer reflects those processes involved in attentional bias per se. If so, this may mean that additional neuronal processing (via emotion or motivation) is required to affect the balance of the impact of top-down and bottom-up information on the priority map.

In their 2005 review, Ernst and Paulus presented a series of key processes that occur during decision making (Ernst & Paulus, 2005). Firstly, a preference among options is initially formed, which is believed to involve a substantial neural network including the parietal cortex (Dehaene, Spelke, Pinel, Stanescu, & Tsivkin, 1999; Ernst et al., 2004; Shadlen & Newsome, 2001), the anterior cingulate cortex (Carter, Botvinick, & Cohen, 1999; Critchley, Mathias, & Dolan, 2001; Lewis & Todd,

2007), the prefrontal cortex (Dias, Robbins, & Roberts, 1997; Glascher et al., 2012; Rushworth, Noonan, Boorman, Walton, & Behrens, 2011), and limbic regions (Bechara, 2004a, 2004b; Critchley, Wiens, Rotshtein, Ohman, & Dolan, 2004). In the current task, this would translate to a preference for selecting a Change or No Change response. Secondly, the execution of an appropriate action based upon the determined preferences is selected. This is believed to involve a more focused network of frontal regions than the first stage of decision making, particularly surrounding the lateral prefrontal cortex (Bechara, Damasio, & Damasio, 2000; Manes et al., 2002; Pierrot-Deseilligny et al., 2003; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004), the anterior cingulate cortex (Botvinick, 2007; Bush et al., 2002; Cohen, Heller, & Ranganath, 2005; Rushworth, Walton, Kennerley, & Bannerman, 2004) and the medial superior frontal gyrus – specifically the pre-supplementary motor area (Forstmann et al., 2008; Humberstone et al., 1997; Rushworth, Behrens, Rudebeck, & Walton, 2007; Rushworth et al., 2004). Here, this translates to participants executing the action of pressing the relevant button of their selected response.

The final stage is the experience or evaluation of an outcome. During this stage, values are attributed to whatever outcomes are experienced by the individual. Here, more stress is placed upon the emotional connotations of an action, and as such, greater emphasis is placed upon feedback loops between frontal regions and regions known to be involved in the processing of emotion and emotion-related decision-making. These include the amygdala (Bechara, Damasio, & Damasio, 2003; Bechara, Damasio, Damasio, & Lee, 1999; Naqvi, Shiv, & Bechara, 2006), nucleus accumbens (Ikemoto & Panksepp, 1999; Lang & Bradley, 2010; Salamone, 1994), orbitofrontal cortex (Plassmann, O'Doherty, & Rangel, 2007; Rolls & Grabenhorst, 2008; Wallis, 2007) and the insula (Clark et al., 2008; Singer, Critchley, & Preuschoff, 2009). In addition, Ernst and Paulus stress a role of the medial prefrontal cortex as part of a feedback system (Euston, Gruber, & McNaughton, 2012; Knutson, Fong, Bennett, Adams, & Homme, 2003; Rogers et al., 2004).

In the current experiment, since participants did not receive online feedback to their responses, the evaluation of an outcome rather than the experience of an outcome is the most likely occurrence. Here, questioning participants regarding their confidence of the accuracy of responses is effectively forcing them to evaluate the outcome of such responses, recruiting feedback loops which could have caused alterations in behaviour. This could mean that results reflect the outcome of an altered attentional setting alongside an internal evaluation of a behavioural response. Consequently, removing the confidence question from the end each trial will allow for a more direct investigation of visual attention and thus will allow us to examine attentional biases more precisely.

In conclusion, the current experiment aimed to discover the optimum paradigm to examine visual attentional biases in non-clinical populations in order to probe the limit of the impact of bottom-up versus top-down information on the priority map via altered attentional control settings. A one-shot change detection paradigm alongside highly controlled visual stimuli was used for more precise manipulation of presented information. This methodology was sensitive enough to detect alterations to attentional control settings following only a single information sheet to induce an attentional bias. It also allowed for the calculation of the early deployment of visual attention via perceptual sensitivity of changes. However, while enquiring about participants' confidence of their response showed increased confidence at detecting bias-related changes, the question may have recruited additional neural processing and feedback-loops relating to decision making. Consequently in its current form, the paradigm is not wholly suitable for its intended task and there is uncertainty regarding the interpretation of the data. Removing this aspect will provide a more direct examination of the cognitive mechanisms underlying visual attentional biases, including the boundary limit of when top-down information carries more weight than bottom-up information and the ease of establishing an attentional control setting. This shall therefore be the paradigm employed during the rest of this thesis.

Chapter 3

Altering attentional control settings causes persistent biases of visual attention

Overview

A single information sheet was found to be sufficient to cause related-items to guide visual behaviour in a top-down manner. However, enquiring about participants' confidence may have recruited emotional and motivational processing. Consequently, the point at which top-down information has a disproportionate influence on visual attention than bottom-up information can be investigated further by removing this question. Following from the success of the previous chapter, a sample of healthy participants was biased towards the colour green by an information sheet. Attentional bias was then assessed using the one-shot change detection task. After an interval of either 1 or 2 weeks participants were then either re-tested on the same change detection task or re-tested on a different change detection task where colour was irrelevant. This included trials in which the distracter stimuli (but never the target) were green. This task thus also addressed the issue of the behavioural relevance of visual information and implicit utility-based training. The key finding was that green stimuli in the second task attracted attention, despite this impairing performance. The attentional bias also persisted for at least two weeks. This persistent attentional bias is arguably the result altered attentional control settings, which are then aided by long-term representations involving contextual cuing. Similar changes to attentional control settings and continuous cuing may relate to all attentional biases observed in the abnormal literature, suggesting that altered attentional control settings may be the cognitive mechanism that underlies attentional bias.

3.1 Introduction

Through the use of a novel one-shot change detection paradigm that provided reaction time, accuracy and a measurement of perceptual sensitivity, the previous chapter investigated the cognitive mechanisms of attentional bias free from methodological or sample conflicts. However, a possible confounding issue was the additional use of a question that required participants to report their confidence on the accuracy of their responses. This may have recruited additional feedback loops involved in decision making requiring additional neuronal processing not related to attention, thus resulting in a task that did not strictly examine the behavioural effects of an attentional bias. Moreover, this thesis seeks to examine the point at which top-down influences on the orienting of visual attention carry more weight than bottom-up influences. The additional motivation triggered by the confidence question also means that it remains unknown if altered attentional control settings can be made independently of emotion and thus, this boundary limit can be tested further. One aim of this chapter is therefore to remedy this potential confound by removing the question on confidence. This will result in a task where responses are related to top-down alterations of incoming information, allowing for the exploration of the point at which top-down information carries more weight than bottom up information on the orienting of visual attention and thus, the cognitive mechanisms of attentional bias.

The previous chapter found evidence suggesting that an attentional bias occurs through the alteration of attentional control settings. However, it is unknown if the adoption of a persistent attentional control setting favouring particular stimuli – i.e. an attentional bias – is dependent on, or influenced by, emotional or other additional processing. Indeed the addiction literature suggests that both attention and additional emotional/motivational processing are required. Janes et al. (2010) employed a smoking-related Stroop paradigm with smokers and non-smokers, while examining neural activity via fMRI. When presented with smoking-related items, smokers showed an increase of activation in areas of the medial temporal lobe associated with the storage and recall of long term memories (Aggleton & Brown, 1999, 2006; Brown & Aggleton, 2001; Scoville & Milner,

1957; Squire & Zola-Morgan, 1991). There was also an increase in activity of the left amygdala and bilateral insula – areas associated with emotional saliency (Phelps, 2004, 2006; Phillips, Drevets, Rauch, & Lane, 2003). The smoking-related words used may have triggered the recall of emotions and emotional memories associated with smoking (or attempts to quit), and these emotional responses may be the cause of the alteration to attentional control settings prioritising smoking-related information.

Alternatively, it is possible that emotional connections towards bias-related items in traditional attentional bias literature and in the previous chapter (due to motivations to approach/avoid stimuli and resulting consequences of biased attention) cause internal representations of stimuli to remain active – at low levels – even when not physically present. This would bias activity in the system, such that incoming sensory information from bias-related stimuli is processed more rapidly (Desimone & Duncan, 1995). However, due to the separation between traditional investigations of maladaptive biases and cognitive investigations of the alterations of attentional control settings, there is need for clarification. If it is possible to both alter attentional control settings in the absence of emotion, and for this alteration to be long-term and specific to a particular category of stimuli, this would provide strong evidence that there is an underlying cognitive foundation of attentional biases which is then presumably strengthened by emotional feedback in abnormal populations.

The current experiment therefore manipulated the goals of observers by initially informing participants that the experiment related to the perception of the colour green in a one-shot change-detection task developed in Chapter 2 (Beck et al., 2006; Beck et al., 2001). Here, a mask interposed between subtly different stimulus arrays is used to induce change blindness (Rensink et al., 1997). However, the question regarding the confidence of participants' responses at the end of each trial has been removed. The behavioural relevance of stimuli was then manipulated during a second experimental session in which the same participants were either retested on the same task, but with the instruction that green was no longer important. To test for the sustainability of the induced

biases, the second testing session occurred either in the same experimental session, after a period of one week, or after a period of two weeks. Using an arbitrary stimulus (the colour green) and not requiring participants to constantly evaluate their success at the task also removes emotions potentially associated with attentional biases, enabling the experiment to ascertain if associations between stimulus and emotion are a requirement for the development and sustainability of attentional biases.

3.2 Experiment 1

3.2.1 Method

3.2.1.1 Participants

Thirty (12 male) undergraduate Psychology students aged 18 to 30 (M: 19.97, SD: 2.44) studying at Durham University participated. All had normal or corrected to normal vision, no colour blindness (assessed via self-report), and gave informed consent with the approval of Durham University Ethics Advisory Committee. Participants were compensated for their time in the form of course credits.

3.2.1.2 Stimuli & Apparatus

All experimental stimuli were programmed in C++ using Borland C++ builder and produced via a VSG ViSaGe box and custom graphics card (Cambridge Research Systems, Rochester, England). They were displayed using a 19“ Sony Trinitron monitor with a resolution of 1024x768 and a refresh rate of 100Hz. Responses were collected via a custom-made two-button button box. Information and consent forms were also used, of which there was a different version for each condition (test or re-test). The biasing test information sheet informed participants that they were carrying out an experiment investigating how the human visual system perceives and processes the colour green, and used the word *green* several times. The neutral re-test sheet informed participants that they were carrying out an experiment investigating how human visual system perceives and processes colour, thus substituting the word *green* for *colour*.

A white fixation cross situated in the centre of a black screen (0.7° x 0.7° visual angle) preceded the test array consisting of a circular (10.2° x 10.2° visual angle) composition of six circles (2.5° x 2.5° visual angle) each of which was one of 8 different equiluminescent colours (green, red, blue, pink, purple, grey, mustard or orange, all 34 cd/m^2). The mask was a black screen.

3.2.1.3 Design

Participants were assigned to one of three groups. All groups received the same information at the start of the experiment and completed the change detection task. Group 1 was then immediately presented with the 2nd, neutral information sheet and asked to complete a second experimental session. Group 2 were invited to return in 1 week. In the 2nd session they were presented with the neutral information sheet then asked to complete the change detection task. Group 3 were invited to return in 2 weeks. In the 2nd session this group was also presented with the neutral information sheet and asked to complete a change detection task. The experiment therefore had a mixed design. There was a within-subjects factor of experimental session (Session 1 v Session 2) and a between subjects factors of Inter Session Interval (0 weeks vs 1 week vs 2 weeks).

3.2.1.4 Procedure

Testing occurred in a darkened room. Participants read the biasing information sheet, and were seated 57cm away from the screen with their heads in a chin rest. Participants were presented with the one-shot change-detection task, where they were informed that their goal was to detect any changes between two sequentially presented arrays. A change was defined as one coloured stimuli changing into a different colour not already present in the array.

The experiment began with the presentation of a fixation cross for 1000ms followed by the stimulus array for 1500ms. The array was then masked for 100ms, after which the stimulus array re-appeared. Stimuli remained present until a response was made. On 25% (45 trials) of trials a green item was present and changed colour (Congruent Change Trials), on 25% of trials a green item was present in the display but a different item changed colour (Incongruent Change Trials), on 25% of

trials no green item was present and one of the other objects changed colour (Neutral Change Trials) and on 25% of trials a green item was present but no change occurred (No Change Trials). The position of the coloured items varied randomly across trials.

Participants were advised that a change could occur to any of the presented stimuli in any position in the array. See Figure 1 for paradigm used in experiment 1. Participants were asked to respond as quickly, but as accurately as possible via the button box if they saw a change (right press) or not (left press). Participants completed 3 blocks of 60 trials with a 5 minute break between each block.

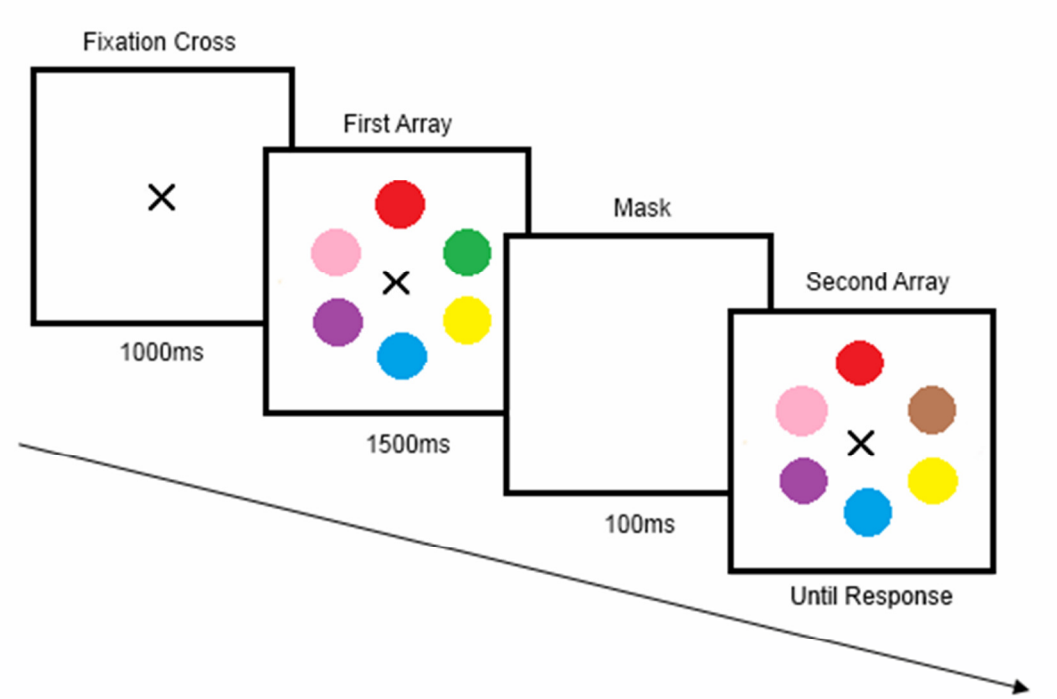

Figure 3.1: Procedure of a typical Congruent Change trial in Experiment 1. A fixation cross was presented for 1000ms, followed by the first array for 1500ms. This was then masked for 100ms before reappearing, where participants had to make their response using the index finger of each hand.

3.2.1.5 Statistical Analyses

Mean reaction times, accuracy, d' scores offering a measurement of perceptual sensitivity, and criterion scores offering a measurement of responder bias (the propensity to report more changes or no changes) were analysed. Several Mixed Factor ANOVAs were completed. In all primary and subsequent analyses, Bonferroni corrections for multiple comparisons were applied.

3.2.2 Results

Outliers with a reaction time above or below 2 standard deviations from the mean were excluded from analyses, resulting in the loss of 0.28% of trials.

3.2.2.1 Reaction Time

Reaction time was entered into a 3 (Inter session Interval: 0 /1 week/2 week) x 3 (Trial Type: Congruent Change/Incongruent Change/Neutral Change) x 2 (Experimental Session: Session 1/Session 2) Mixed Factor ANOVA. Trial and Session were within-subjects factors; Inter Session Interval was between-subjects. The only significant result yielded by the ANOVA was a main effect of Trial Type: $F(2,54) = 10.490$, $p < .001$, $r = .403$. Reaction times for Congruent Change trials were significantly faster (M: 685.968ms) than reaction times for Neutral Change trials (M: 790.867ms, $p = .003$, $r = .534$) and Incongruent Change trials (M: 859.178ms, $p<.001$, $r = .610$). Reaction times of Incongruent compared to Neutral Change trials did not differ.

3.2.2.2 Accuracy

Accuracy was also entered into a 3 (Inter session Interval: 0 /1 week/2 week) x 3 (Trial Type: Congruent Change/Incongruent Change/Neutral Change) x 2 (Experimental Session: Session 1/Session 2) Mixed Factor ANOVA. Trial and Session were within-subjects factors; Inter Session Interval was between-subjects. Mirroring the results in the reaction time analysis, the only observed effect was a significant main effect of Trial Type: $F(2,54) = 60.874$, $p < .001$, $r = .728$. Accuracy in Congruent Change trials was significantly higher (M: .871) than accuracy in Neutral Change trials (M: .726, $p<.001$, $r = .842$) and Incongruent Change trials (M: .662, $p<.001$, $r = .868$). Furthermore, accuracy in Neutral Change trials was significantly higher than accuracy in Incongruent Change trials ($p = .001$, $r = .592$).

3.2.2.3 d'

Participants' perceptual sensitivity to detect changes was calculated using d', and allowed for rates of False Alarms and Correct Rejections in No-Change trials to be taken into account. These scores were then entered into a 3 (Inter session Interval: 0 /1 week/2 week) x 3 (Trial Type: Congruent

Change/Incongruent Change/Neutral Change) x 2 (Experimental Session: Session 1/Session 2) Mixed Factor ANOVA. Trial and Session were within-subjects factors; Inter Session Interval was between-subjects.

There was a significant main effect of Trial Type: $F(2,54) = 9.979$, $p < .001$. d' scores for Congruent Change trials were significantly higher (M: 3.671) than d' scores for Neutral Change trials (M: 2.914, $p = .033$, $r = .466$) and Incongruent Change trials (M: 2.608, $p<.001$, $r = .847$) – see Table 1 for accuracy. There was also a significant main effect of Session: $F(1,27) = 6.824$, $p = .015$. d' scores in the re-test condition were higher by an average of .602 ($r = .428$). Since participants all received this condition after initial testing, this could be evidence of an overall practice effect. No Trial x Session interaction was observed: $F(2,54) = .035$, $p = .966$.

There was also a main effect of Inter Session Interval: $F(2,27) = 5.852$, $p = .008$, however, this did not interact with any other variable (Session: $F(2,27) = 1.730$, $p = .196$; Trial: $F(4,54) = 1.012$, $p = .409$; Session x Trial: $F(4,54) = .191$, $p = .942$). Pairwise comparisons revealed that mean d' scores for 0 Weeks were significantly higher than 2 Weeks (mean difference: 1.472, $p = .006$, $r = .422$). To examine if time was the intervening factor in the persistence of the bias effect rather than experience with the task, an additional analysis was undertaken examining d' scores of session 2 only for each type of trial in a block-by-block analysis. Thus, d' scores in Session 2 were entered into a 3 (Trial Type: Congruent Change/Incongruent Change/Neutral Change) x 3 (Experimental Block: Block 1/Block 2/Block 3) Within Factor ANOVA. As expected, there was a significant main effect of Trial Type: $F(2,58) = 35.851$, $MSE = .787$, $p < .001$. d' scores for Congruent Change trials were significantly higher (M: 3.620) than d' scores for Neutral Change trials (M: 2.753, $p <.001$, $r = .742$) and Incongruent Change trials (M: 2.572, $p <.001$, $r = .783$). There was no main effect of Experimental Block ($F(2, 58) = 1.350$, $MSE = 1.849$, $p = .267$) and no Trial Type x Experimental Block interaction ($F(4, 116) = .391$, $MSE = .377$, $p = .814$).

Table 3.1
Mean hit rate across all types of trial and mean correct rejection/false-alarm rates for no-change trial when a green stimulus was either present or absent

Trial Type	*Hit Rate*	*Correct rejection rate*	*False-alarm rate*
Congruent Change	87.09	90.72	9.28
Incongruent Change	66.22	90.72	9.28
Neutral Change	72.65	93.30	6.70

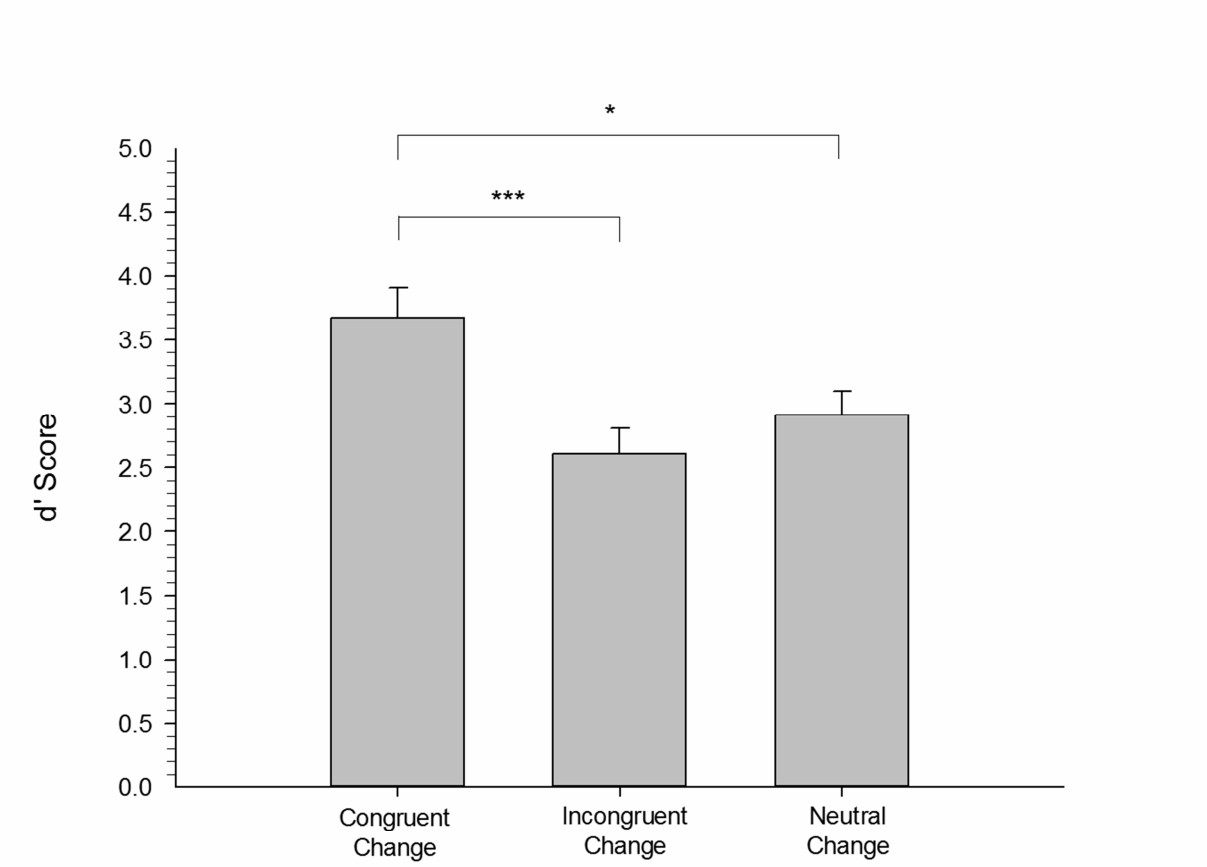

Figure 3.2: Effect of induced attentional bias on d' in a change detection task. Higher d' indicates greater sensitivity to change. Sensitivity is higher in Congruent Change trials than both Incongruent and Neutral change trials. This difference is larger in Congruent compared to Incongruent Change trials, thus attention is captured by a biased stimulus, and it also distracts from detecting other changes. Error bars show standard error of the mean. *Note:* * p<.05, *** p<.001

3.2.2.4 Criterion Scores

Criterion scores of participants were entered into a 3x2x2 Mixed Factor ANOVA with factors and levels the same as all previous ANOVAs. There was a main effect of trial: $F(2, 54) = 10.037$, $p<.001$, $r = .396$. Pairwise comparisons revealed that criterion scores for Congruent Change trials were significantly lower (M: .315) than those of Incongruent (M: .806, $p <.001$, $r = .804$), and Neutral

Change trials (M: .799, p = .017, r = .502). Criterion scores of Incongruent compared to Neutral Change trials did not differ. No other significant results were present. Since a lower criterion indicates more liberal responding (i.e., more likely to give a Change response), this suggests that participants were likely to report that there was no change unless a green item changed colour.

3.2.3 Effect of Confidence Question

In the previous chapter, it was speculated that enquiring about participants' confidence may have affected the way in which participants respond to the task, recruiting the use of additional feedback loops in decision making. Since attentional biases are implicit cognitions (Ryan, 2002), the recruitment of feedback loops forcing participants to explicitly think about their behaviour would suggest that these results no longer reflect the phenomenon. Furthermore, the effects of the information sheet on perceptual sensitivity may be different with the confidence question asked at the end of each trial compared to if confidence of response is not asked. It was therefore necessary to establish if the confidence question caused a behavioural effect. If so, findings from the current chapter would be more indicative of an attentional bias towards the colour green.

A 2 (Confidence: Asked/Not Asked) x 2 (Experimental Session: Session 1/Session 2) x 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) Mixed Factor ANOVA was therefore carried out comparing the effect of the confidence question on perceptual sensitivity between a comparable group of participants. The groups chosen were the Bias then Neutral group from the previous chapter, along with the 1 Week Inter Session Interval group from the current chapter. Both of these groups of participants received the biasing information in their first experimental session then were re-tested after one week where they were presented only with the neutral information sheet. Thus, the only experimental difference between the two groups was the addition of the confidence question in the Asked group of participants. Confidence was a between groups factor and both Experimental Session and Trial were within groups factors.

The ANOVA revealed a significant three-way interaction between Confidence, Experimental Session and Trial: $F(2, 36) = 11.262$, $p<.001$, $r = .488$. This was further examined via two repeated measures ANOVAs comparing the interaction between Experimental Session and Trial separately for each of the two Confidence groups. For the Not Asked group, d' scores for each type of trial did not differ between Experimental Session 1 and 2 ($F(2, 18) = .095$, $p = .910$, $r <.072$). Thus when there is no question regarding how confident participants were with the accuracy of their responses, the behavioural effects of the green information sheet did not differ between the two experimental sessions.

However, the ANOVA for the Asked group revealed a significant interaction between Experimental Session and Trial: $F(2, 18) = 40.675$, $p<.001$, $r = .481$. This was further investigated via two one-way Repeated Measures ANOVAs examining perceptual sensitivity in each type of trial separately for Experimental Session 1 and then 2. For Experimental Session 1 the ANOVA revealed a significant effect of Trial on perceptual sensitivity: $F(2, 18) = 18.323$, $p<.001$, $r = .710$. Here, d' scores for Congruent Change trials were significantly higher (M: 5.032) than d' scores for Incongruent (M: 3.634, $p = .006$, $r = .767$) and Neutral (M: 2.103, $p = .001$, $r = .842$) change trials. d' scores of Incongruent compared to Neutral trials were significantly higher ($p = .004$, $r = .788$). For Experimental Session 2 the ANOVA also revealed a significant effect of Trial on perceptual sensitivity: $F(2, 18) = 4.039$, $p = .036$, $r = .428$. Here, d' scores for Congruent Change trials were significantly higher (M: 2.493) than d' scores for Incongruent Change trials (M: 2.092, $p = .024$, $r = .671$). However, unlike for experimental Session 1, in Experimental Session 2 perceptual sensitivity of Congruent compared to Neutral trials did not differ ($p = .240$, $r = .386$), driving the three-way interaction. Additionally, d' scores of Neutral Change trials were significantly higher (M: 3.066) than those of Incongruent Change trials ($p = .023$, $r = .674$).

3.2.4 Interim Discussion

Firstly, enquiring about participants' confidence of their accuracy had an effect when participants returned for their second testing session. Both the group of participants asked about their confidence and those not asked had increased perceptual sensitivity of Congruent compared to Incongruent change trials. However, when participants are asked to report how confident they were with the accuracy of responses, the significant alteration in perceptual sensitivity between Congruent and Neutral trials seen in Chapter 2 disappeared. It therefore seems reasonable to assume that the confidence question did alter the cognitive processes used following the presentation of an information sheet. Thus removing the question allows for a more direct analysis of attentional bias and the cognitive mechanisms resulting from altering attentional control settings.

On first inspection these results appear to extend those of Chapter 2 in that it is possible to induce a non-emotional attentional bias in healthy participants. Presenting participants with an information sheet about the colour green biased participants towards this colour. Attention was captured by the green object, which improved perceptual sensitivity on trials where the green object changed. Performance on trials where a green object was present, but the change occurred at a different location was also impaired, since attention was captured by the unchanged green object resulting in missed changes elsewhere. Furthermore, this bias persisted for at least two weeks. However, it should be noted that responder bias, reaction times and perceptual sensitivity in Incongruent Change trials was not significantly different or more impaired than Neutral Change trials, suggesting that performance was not more impaired when a green item was present but not relevant. Nevertheless, accuracy and the effect sizes observed in the d' analysis do suggest greater sensitivity in Congruent compared to Incongruent trials than Congruent compared to Neutral trials.

A further possibility is that since no change trials always include a green item, a search strategy could have been adopted wherein participants scan the initial array and if no green item was present, know it was going to be a change trial and answer accordingly. However, such a possibility is unlikely since if a strategy was utilised, accuracy of Neutral Trials would be at or near ceiling. Table

1 shows that the overall accuracy of Neutral Change trials in Experiment 1 is 72.65%. This is lower than the accuracy of Congruent Change trials (87.09%); a pattern reflected in d' scores. Furthermore, the block-by-block analysis showed no interaction between experimental block and trial type, thus participants' sensitivity at detecting Neutral Change trials did not improve as the experiment progressed. Consequently, the possibility of participants adopting a search strategy is not supported.

However, the data need to be analysed with caution for the following reasons. Although participants were explicitly told that colour was irrelevant in the 2nd session they may still have consciously implemented a 'select green' strategy because it had been successful in the 1st session. There is evidence that participants have a tendency to persist with previously successful problem-solving strategies even when they are no longer effective (Crone, Bunge, van der Molen, & Ridderinkhof, 2006). Furthermore, the change was likely to occur on the green item on 25% of trials, but there were seven other items so the probability of the change occurring at a non-green item was only 11%. In other words, changes were twice as likely to occur at a green item as any other item. It therefore makes sense for the participant to attend the location where there is the highest probability of a change occurring. In this case, it is difficult to know whether the improved performance for green items during the second session was due to an unconscious attentional bias free from emotion or motivation to succeed or a conscious decision to attend to the colour green.

Additionally, a robust induced bias effect would be determined by little or no difference in behaviour between the three differences in inter-test interval between the test and re-test sessions. The d' analysis revealed that participants who were tested and re-tested in the same week had a higher d' than those who had a two-week gap in between. Generalised practice effects or perceptual learning could explain this difference, since having all six blocks of trials in the same session could allow participants to become better at the task than those with a one- or two-week gap in between. The fact that no difference between inter-test interval and condition was present suggests a robustness of the biasing effect. Moreover, the fact that d' scores in Session 2 did not wane across the three

blocks of trials suggests that task experience is not having an effect on the induced attentional bias towards green objects.

In order to rule out the explanation that participants volitionally attended to the green item a second experiment was conducted in which attentional bias was tested under conditions where the change never occurred at the green item. In this case, attending to green would never lead to successful change detection. Moreover, because attentional bias causes a capture of attention by both task relevant (Jones et al., 2005) and task irrelevant items (Stormark et al., 1997), this additional task also allowed for the investigation of the distractibility of induced bias-related objects when task irrelevant.

3.3 Experiment 2

3.3.1 Method

3.3.1.1 Participants

Participants were 30 (10 male) undergraduate Psychology students aged 18 to 56, (M: 25, SD: 8.08) studying at Durham University. All had normal or corrected to normal vision, no colour blindness, gave informed consent with the approval of Durham University Ethics Advisory Committee and were compensated for their time via course credits.

3.3.1.2 Stimuli & Apparatus

Stimuli production and presentation apparatus was identical to experiment 1, as were the biasing information and consent forms. Thus, the biasing test information sheet for session 1 informed participants that they were carrying out an experiment investigating human perception of the colour green, and used the word *green* several times. The shape task information and consent forms substituted the word *colours* for *shapes* and *green* for *shape,* informing participants that they were carrying out an experiment investigating how human visual system perceives and processes shape. There was also an additional paragraph stressing the focus on shape and emphasising that colour was task-irrelevant (see Appendix C). The sheet did not mention the word *green*.

Stimuli in session 1 were identical to those used in experiment 1. For the shape task, the array (10.2° x 10.2° visual angle) comprised four different shapes (square, circle, triangle, pentagon or trapezium: visual angle: 2.5° x 2.5°), all of a different equiluminescent colour (34 cd/m^2). The mask was a completely blank screen.

3.3.1.3 Design

Participants were again assigned to one of three groups. All groups received the same information at the start of the experiment and completed the change detection task. Group 1 was then immediately presented with the 2nd session – the shape information sheet – and asked to complete a different experiment on the perception of shapes. It was stressed that colour was irrelevant to the task. Group 2 were invited to return in 1 week. In the 2nd session they were presented with the shape information sheet then asked to complete the shape change detection task. Group 3 were invited to return in 2 weeks. In the 2nd session this group were also presented with the shape information sheet and asked to complete the shape change detection task. The experiment therefore had a mixed design. There was a within-subjects factor of experimental session (Session 1 v Session 2) and a between subjects factors of Inter Session Interval (0 weeks vs 1 week vs after 2 weeks).

3.3.1.4 Procedure

Procedure for session 1 was identical to that used in experiment 1, in that participants were presented with the biasing information sheet and asked to complete the six-circle experimental task. In session 2, participants were again asked to detect changes between two sequentially presented arrays of stimuli, separated by a mask. Here, changes were defined as a shape in the array changing into a different shape, with the colour of shape never changing. The shape experiment began with the presentation of a fixation cross for 1000ms followed by the stimulus array for 750ms. The array was then masked for 100ms, after which the stimulus array re-appeared. Stimuli remained present until a response was made. On 25% (120 trials) of trials a green shape was present, but a different shape changed shape, (Green Present Change Trials), on 25% of trials a green item was present but

no change occurred (Green Present No-Change Trials), on 25% of trials no green item was present and one of the shapes changed shape (Green Absent Change Trials) and on 25% of trials no green item was present and no change occurred (Green Absent No Change Trials). The position of the coloured items was varied randomly across trials.

Participants were advised that a change could occur to any of the presented shapes in any position in the array. See Figure 3.3 for paradigm used in the shape change detection task. Participants were asked to respond as quickly, but as accurately as possible via the button box if they saw a change (right press) or not (left press). Participants completed 6 blocks of 80 trials with a 5 minute break between each block.

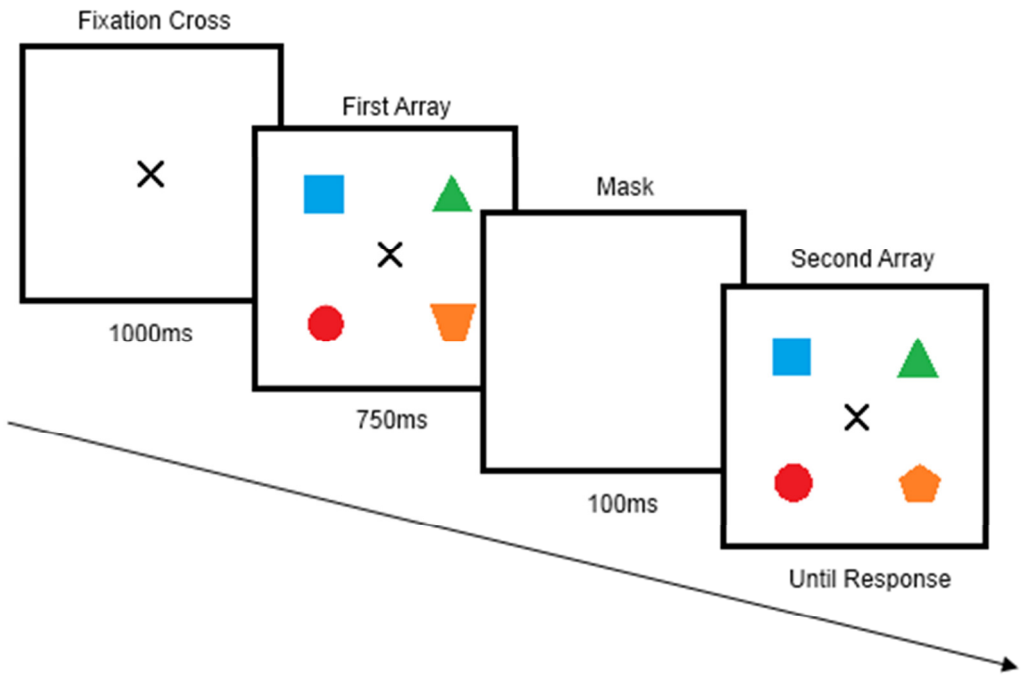

Figure 3.3: Procedure of a typical trial in Experiment 2. Figure shows a Green Present Change trial. A fixation cross was presented for 1000ms, followed the first array for 750ms. This was then masked for 100ms before reappearing, where participants had to make their response, using the index finger of each hand

3.3.2 Results

3.3.2.1 Session 1

d' scores from Session 1 (the initial colour experiment following the presentation of the biasing information sheets) were entered into a 3 (Inter Session Interval Group: 0 /1 week/2 week) x 3 (Trial Type: Congruent Change/Incongruent Change/Neutral Change) Mixed Factor ANOVA to ensure that

an attentional bias towards green items was initially present. Trial was a within-subjects factor; Inter Session Interval Group was between-subjects. The results show a significant main effect of Trial Type: F(2, 54) = 40.140, p <.001. d' Scores of Congruent Change trials were significantly higher (M: 2.624) than d' scores of Incongruent (M: 1.633, p <.001, r = .806) and Neutral Change (M: 1.725, p<.001, r = .812) trials. There was no effect of Inter Session Interval Group: F(2, 27) = .128, p = .880, and no Trial Type x Inter Session Interval Group interaction: F(4, 54) = .279, p = .890. Thus, it was concluded that a successful inducement of an attentional bias towards green items in all groups occurred.

3.3.2.2 Session 2

Trials with a reaction time above or below 2 standard deviations from the mean were deemed outliers and were excluded from analyses, resulting in the loss of 0.35% of trials.

3.3.2.2.1 Reaction Time

Reaction time was entered into a 3 (Inter Session Interval: 0 /1 week/2 week) x 2 (Bias: Green Present/Green Absent) x 2 (Trial Type: Change/No Change) Mixed Factor ANOVA. Bias and Trial were within-subjects; Inter Session Interval was between-subjects. A main effect of Bias was observed: F(1,27) = 13.539, p = .001. Mean reaction time when a bias shape was present was 781.30ms as opposed to 655.43ms when no bias shape was present (r = .578). There was also an interaction between Bias and Trial: F(1,27) = 13.485, p = .001. To clarify this effect on reaction time, reaction times were normalised with respect to bias (bias present – no bias present/no bias present * 100). The presence of a green shape in change trials caused an increase in reaction time by an average of 23.21% (r = .574). For no change trials, the presence of the green shape caused an average increase reaction time by 9.02% (r = .469). There was no main effect of Inter Session Interval: F(2,27) = 1.428, p = .257. Furthermore, Inter Session Interval did not interact with any other variable. Moreover, when examining reaction times in a block-by-block analysis via a 2 (Bias: Green Present/Green Absent) x 2 (Trial Type: Change/No Change) x 6 (Experimental Block: Block 1/Block 2/Block 3/Block 4/Block 5/Block 6) Within Factor ANOVA, Experimental Block did not interact with Bias: F(5, 145) =

1.486, p = .220, suggesting that the slowing of participant reaction times when a green shape was present did not wane across the duration of the experimental session.

3.3.2.2.2 Accuracy

Accuracy was also entered into a 3 (Inter Session Interval: 0 /1 week/2 week) x 2 (Bias: Green Present/Green Absent) x 2 (Trial Type: Change/No Change) Mixed Factor ANOVA. Bias and Trial were within-subjects; Inter Session Interval was between-subjects. A main effect for Bias was observed: $F(1,27) = 19.465$, $p<.001$. Accuracy when a green shape was present was significantly lower (M: .738) than accuracy when no green shape was present (M: .785, r = .647). There was also a main effect of Trial: $F(1,27) = 39.900$, $p<.001$. Accuracy in Change trials was significantly lower (M: .659) than accuracy in No Change (M: .864, r = .772). Bias and Trial also interacted: $F(1, 27) = 30.029$, $p<.001$, r = .726. To elucidate, the effect of the presence of a green shape in Change trials was examined, followed by an analysis of the effect of the presence of a green shape in No Change trials. In Change trials, there was a significant effect of the presence of a green shape: $F(1, 27) = 32.253$, $p<.001$. Accuracy when a green shape was present was significantly lower (M: .593) than accuracy when no green shape was present (M: .725, r = .738). In No Change trials, the presence of a green shape also had a significant effect: $F(1, 27) = 8.802$, $p = .006$. Accuracy when a green shape was present was significantly higher (M: .883) than accuracy when no green shape was present (M: .845, r = .496). No other effects were observed.

3.3.2.2.3 d'

Participants sensitivity to changes was calculated using d'. This was entered into a 3 (Inter Session Interval: 0 /1 week/2 week) x 2 (Bias: Green Present /Green Absent) Mixed Factor ANOVA. Trial was within-subjects; Inter Session Interval was between-subjects. Mean d' scores when a bias shape was present was 1.5407, as opposed to 1.7214 with no bias shape present. The ANOVA revealed that this difference was significant: $F(1, 27) = 4.667$, $p = .04$, r = .383. Figure 4 displays this effect, while Table 2 displays the mean accuracy. There was no main effect of Inter Session Interval: $F(2,27) = .638$, MSE = .266, $p = .536$, or a Bias x Inter Session Interval interaction: $F(2,27) = .397$, MSE = .105, $p = .676$.

Again, to examine if time was the intervening factor in the persistence of the bias effect, a block-by-block analysis was carried out by entering mean d' scores into a 2 (Bias: Green Present/Green Absent) x 2 (Trial Type: Change/No Change) x 6 (Experimental Block: Block 1/Block 2/Block 3/Block 4/Block 5/Block 6) Within Factor ANOVA. The main effect of Bias remained: $F(1, 29) = 9.144$, $MSE = .551$, $p = .005$, with d' scores of Bias Present trials significantly lower than Bias Absent trials by an average of .236. The ANOVA revealed no main effect of Experimental Block: $F(5, 145) = 1.781$, $MSE = .374$, $p = .120$ and Bias x Experimental Block interaction: $F(5, 145) = 1.485$, $MSE = .267$, $p = .198$, suggesting that the induced bias did not wane across experimental blocks.

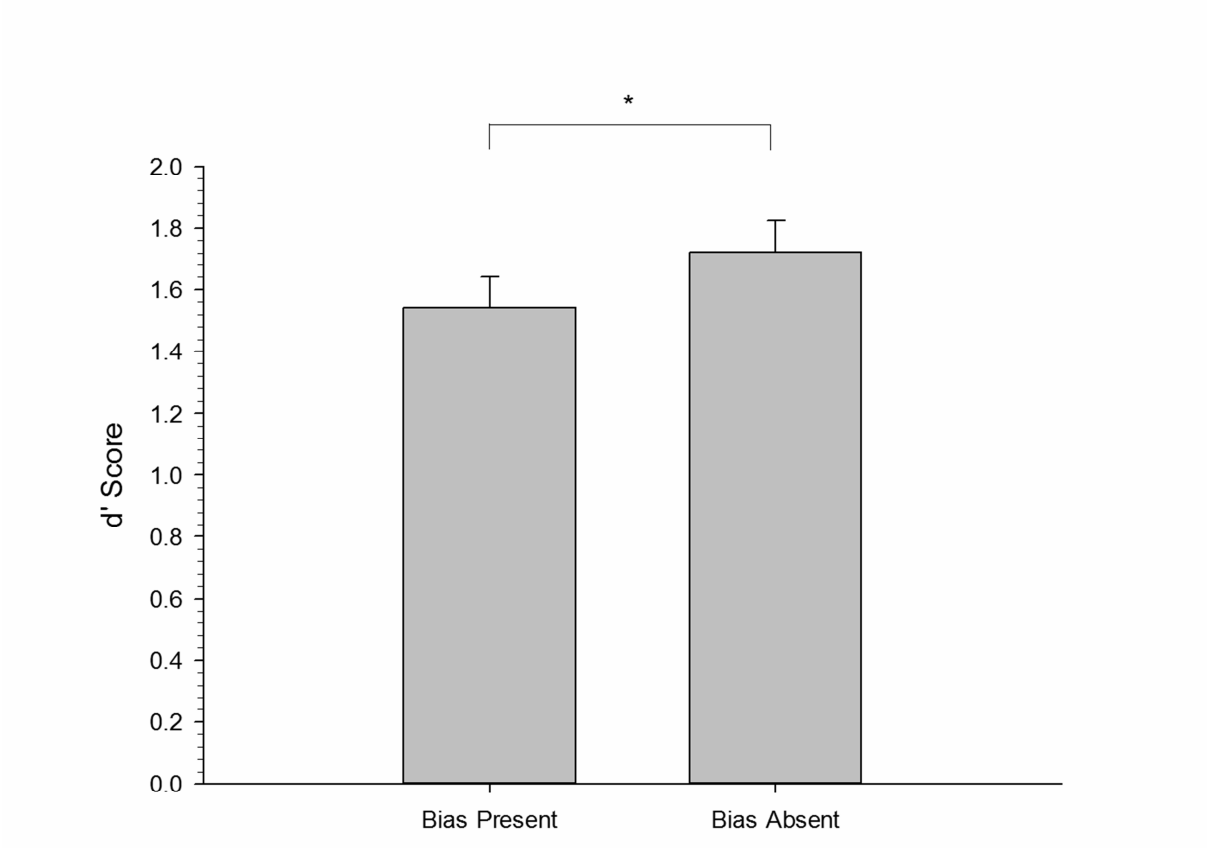

Figure 3.4: Effect of the presence of a biased stimulus (a green shape) on d' when colour is task-irrelevant. Higher d' indicates greater sensitivity to change. Participants are distracted from detecting other changes when a green stimulus is also present. Error bars show standard error of the mean. *Note:* * p<.05

Table 3.2
Mean hit rate across both types of change trial and mean correct rejection/false-alarm rates for no-change trial when a green stimulus was either present or absent

Bias Type	*Hit Rate*	*Correct rejection rate*	*False-alarm rate*
Green Present	59.29	88.32	11.68
Green Absent	72.54	84.46	15.54

3.3.2.2.4 Criterion Scores

Criterion scores were analysed in a Mixed Factor ANOVA with factors and levels the same as those in the d' analysis. A main effect of bias was observed: $F(1,27) = 13.398$, $p=.001$. Criterion scores when a green shape was present was .483, compared to .204 with no green shape present ($r = .516$). This suggests that the presence of a green shape caused participants to become more conservative with their responses. No other effects were observed.

3.3.3 Interim Discussion

The evidence indicates that the induced attentional bias had extended beyond the immediate experimental situation, despite colour now being explicitly irrelevant. This result argues against the suggestion that participants were simply choosing to attend to the green item. Reaction times were substantially slower in trials with a green shape present, and accuracy was impaired when a shape in the array changed, but green was also present. Accuracy was improved in no change trials when a green shape was present, probably because attention was biased towards the green shape. These differences in behaviour would seem to be due to the induced attentional bias decreasing participants' sensitivity to detect change when a green shape is present, as evidenced by d'. This is because the green item when presented captures attention, thus diverting attention away from the visual transient. This manifests in lowered accuracy in green present change trials and slower overall reaction times when a green shape is present.

While participants in the Same Week condition may have still been using an 'attend green' strategy, since this would have been beneficial in their previous experimental block (the initial six-circle task),

the length of time between biasing and subsequent re-testing had no significant effect on reaction time or sensitivity to detect change. This suggests that all experimental groups would have been using the same strategy when completing the shape task. With two weeks between Session 1 and Session 2 for some participants, it seems unlikely that these participants were still using a 'select green' strategy, suggesting a less transient effect is taking place. Additionally, the lowered perceptual sensitivity did not dissipate across experimental blocks, suggesting that task experience is not an influencing factor in the persistence of the bias. Even more, the generalisation of the induced bias from one experimental paradigm to another suggests that the induced bias is also robust.

Nevertheless despite these promising findings, it is possible that the ratio of Congruent Change trials in session 1 wherein participants read the biasing information sheet before carrying out the task may have also played a role in the establishment of an attentional control setting to favour the processing of green items. In other words, there may have been an added motivation to attend to green items. It is possible that participants implicitly learn to attend to green items in session 1 because this gives a behavioural advantage, and that the success of this adopted strategy simply carries over to the shape task. Thus, the altered attentional control settings may have little to do with the biasing information sheet and may simply be related to a probability-based learning mechanism. Consequently, there is a risk that the observed findings do not reflect the inducement of an attentional bias (the adoption of an attentional control setting) independent of emotion or motivation. In order to establish if this probability based learning can occur independently of the initial information sheet, an additional control experiment was carried out. Here, participants receive the identical change-detection task used in session 1 of experiments 1 and 2; however they only receive a neutral instruction sheet.

3.4 Control Experiment

3.4.1 Method

3.4.1.1 Participants

Participants were 10 (3 male) undergraduate Psychology students aged 18 to 27, (M: 20.4, SD: 3.134) studying at Durham University. All had normal or corrected to normal vision, no colour blindness, gave informed consent with the approval of Durham University Ethics Advisory Committee and were compensated for their time via course credits.

3.4.1.2 Stimuli, Apparatus, Design & Procedure

Stimuli production and presentation apparatus was identical to session 1 of experiments 1 and 2; however information and consent forms were neutral. The information sheet for this experiment therefore only informed participants that they were carrying out a change-detection experiment investigating how the human visual system processes colour; there was no mention of the word *green*. Stimuli were identical to those used in both session of experiment 1, and session 1 of experiment 2.

All participants received the same information at the start of the experiment and completed the single change detection task. The experiment therefore had a within subjects design. There was a single factor of Trial (Congruent Change v Incongruent Change v Neutral Change v No Change). The procedure was identical to that used in experiment 1 and session 1 of experiment 2, with the only alteration being the information and consent forms presented to participants. Here, participants were presented with a neutral information sheet and asked to complete the six-circle experimental task. The number of blocks, trials per block and ratio of each type of trial was kept the same.

3.4.2 Results

Trials with a reaction time above or below 2 standard deviations from the mean were deemed outliers and were excluded from analyses, resulting in the loss of 0.32% of trials.

3.4.2.1 d'

Calculated d' scores using No Change trials to assess hit and false alarm rates were entered into a one-way ANOVA with a single within subjects' factor of Trial Type (Congruent Change/Incongruent Change/Neutral Change). The ANOVA revealed no significant main effect of Trial Type: $F(2, 18) = .969$, MSE = .093, $p = .399$, $r = .226$. Furthermore, the effect sizes of the comparison of each Trial Type with each other suggests that participants were not adopting any sort of strategy or were implicitly biased towards detecting green changes via a probability-based learning mechanism. Comparing Congruent Change trials against Incongruent Change trials, the effect size was $r = .240$ ($p = .478$); comparing Congruent Change trials against Neutral Change trials the effect size was $r = .340$ ($p = .307$). Finally comparing Incongruent Change trials against Neutral Change trials, the effect size was $r = .284$ ($p = .397$).

3.4.3 Interim Discussion

The results from this control experiment offer strong evidence that no bias towards any colour exists if participants are given a neutral information sheet before the change detection task. As such, the carry-over effects from the initial biasing session to the shape session in experiment 2 is due to the word prime on the information sheet and not due to probability-based implicit learning or an added motivation to attend to green. Consequently, this control experiment provides evidence that the biasing information sheet is at the root of the behavioural changes observed in experiments 1 and 2, and thus is the cause of the attentional bias towards selecting green items for further processing. Furthermore, while it is impossible to control for the qualia of individual colour experiences between participants, this experiment strongly suggests that no natural bias towards green exists. Therefore our stringent controls involving the size, visual angle and luminance of stimuli were successful meaning that the results observed in experiments 1 and 2 were not due to green items simply standing out more over other items in the arrays.

3.5 Discussion

The current experiments have expanded upon the findings in the previous chapter, by discovering that a single information sheet is sufficient to induce a persistent attentional bias in the absence of emotion and motivation. This attentional bias was found to alter participants' sensitivity to detect bias-related changes, lasts for at least two weeks and is robust such that it interferes with processing in other tasks when colour is made both explicitly and implicitly irrelevant. This was done by altering participants' internal representations of items since no external alterations to the stimuli were made, thus the bias must have been caused by some top-down influence. Importantly, this top-down modulation cannot be due to the current goals or motivations of participants, since attending to colour in the shape task went against the behavioural goal to detect changes to shapes and no question of confidence was present. It is believed that this top-down influence reflects a persistent alteration to an attentional control setting towards the arbitrary stimulus, raising their representation on the priority map and allowing related items to be preferentially processed.

The control experiment wherein participants were provided with only a neutral information sheet before carrying out the initial change detection task also provides further insight into the conclusions that can be drawn from the current study. In Session 1 of all experiments, participants are biased via an information sheet, and then the usefulness of attending to green items is reinforced due to the ratio of Congruent Change trials. It could therefore be argued that the persistence of the bias stems from a combination of the information sheet presented to participants and the added motivations relating to the effectiveness of attending to green. However, the results from the control experiment show that the utility of attending to green items is not sufficient to alter attentional control settings – participants required the biasing information sheet as well in order for the attentional bias to form. Thus, an attentional bias towards green was not implicitly formed via a probability-based training mechanism or from participants learning that attending to green items in Session 1 gives them an advantage in the task.

These findings support the argument that altered attentional control settings are a common cognitive mechanism of attentional bias. The information sheet encouraged participants to adopt an attentional control setting favouring green stimuli. Since nothing occurs to cancel this setting, it remains in place at the time of the second testing session. However, this chapter advances the findings from Chapter 2 by establishing that the altered attentional control settings (Folk et al., 1992) can be formed in the absence of additional feedback loops relating to subsequent decision making, that the alterations persist for at least two weeks, and that these alterations transfer to a task in which attending to green is behaviourally disadvantageous. This altered attentional setting has caused a modification of participants' internal states, influencing the representations of green items on the priority map and raising the likelihood that they will go on to capture attention (Awh et al., 2012; Fecteau & Munoz, 2006). The current experiment shows that participants adopt an attentional control setting in response to the first instruction sheet (about the colour green). This resulted in items related to the bias – in this case, green items – being preferentially passed through the attentional filter, meaning green items went on to effortlessly capture attention in the absence of any additional motivations to attend to green. Thus, the bias was an unconscious result of the information sheet provided to participants, highlighting the ease at which attentional control settings can be altered and showing that the balance between the impact of top-down and bottom-up information on the priority map can be easily swayed.

Both the current experiments and the findings from Chapter 2, however, have found that a long-term switching of attentional settings via explicit instructions is easy to induce even with non-emotive stimuli. These results mirror those observed within the traditional attentional bias literature, wherein individuals are unable to suppress or alter their attentional control settings which favour pathology-related items (Schoenmakers, Wiers, Jones, Bruce, & Jansen, 2007). This is particularly so for Experiment 2, where attending to green items caused an impairment in behaviour since it distracted from the primary goal to detect shape changes. This offers further support that the adoption of attentional settings favouring a particular category of stimulus is a common

cognitive underpinning of attentional bias that transcends the particular pathological subgroups it is more commonly studied within. However, since this experiment does not directly analyse any psychopathological sub-groups, these conclusions are speculative.

It could be argued that the results in this chapter (and the previous chapter) are due to participants holding the items in working memory, or participants' working memory representations of the stimuli being reactivated when brought back to the lab for the second session of testing. However, the findings from this chapter show that this explanation is unlikely since the biasing effects for both the colour and shape tasks were still present two weeks after initial biasing, whereas in order for working memory to have an effect on attention, the active maintenance of stimuli is required (Downing & Dodds, 2004; Soto & Humphreys, 2006; Soto et al., 2006). In the current experiments, there was no requirement of participants to hold any items in working memory, when they were informed that they were partaking in a completely different task where colour was irrelevant (Experiment 2). Thus, it seems unlikely that the results of this study are due to the effects of maintaining the items in working memory.

However, while the active maintenance of items in working memory is unlikely to account for these findings, there is an alternative explanation that shares some parallels. In the current experiments (and in Chapter 2), participants' attentional control settings may have been cued by the context in which they received the initial task instructions, and then simply reactivated when they returned for their second experimental session. A recent study has found that the persistence of the chosen attentional control setting can be determined by the context in which they receive a particular task (Cosman & Vecera, 2013). Here, participants were procedurally trained to use either the Singleton Detection Mode or Feature Search Mode attentional setting within the same training session but in separate blocks on different, irrelevant contextual backgrounds (cityscape/forest scene). In the test phase, the search mode favoured by participants in ambiguous blocks (wherein either search mode could be used) was determined by the irrelevant background on which the trials were presented.

This suggests that activated attentional settings depend on long-term memory representations (Carlisle, Arita, Pardo, & Woodman, 2011) that are aided by the initial context in which the learning of an optimum strategy for a task takes place.

Cosman and Vecera's (2013) findings suggest that participants in the current experiments, returning to the same lab for their second experimental session may have acted as a cue, which reactivated their attentional control settings favouring green items. If so, contextual long-term memory cues can not only aid in the abstract learning of when to utilise a particular search mode (Cosman & Vecera, 2013), but can also aid the development of an attentional bias towards particular stimuli features. This is particularly observed in Experiment 2, where participants were explicitly told to ignore colour and focus on shape, yet were still biased towards green items. Here, active working memory representations and executive functioning failed to fully override long-term alterations of the attentional set that modulated the top-down processing of certain features. However, Cosman and Vecera (2013) procedurally trained participants to use a search strategy that optimised performance, whereas the current studies used only an information sheet. Although the attentional control setting activated in the current experiments initially optimised performance, the use of this strategy resulted in worsening performance in the shape task. Moreover, this strategy was not procedurally learned in the absence of experimental information (the Control experiment). It is possible that contextual cuing to reactivate an attentional control setting needs to occur in addition to a training phase relying on online feedback to participants which could have activated the decision making feedback loops discussed in chapter 2 (Ernst & Paulus, 2005).

Nevertheless, Cosman and Vecera's finding do offer a potential explanation regarding the sustainability of attentional biases in the addiction literature (Field et al., 2007; Schoenmakers et al., 2007). In such cases, attentional control settings may be permanently cued towards bias-related items via long-term memory representations (Janes et al., 2010). However again, this possible link

into the abnormal literature is tenuous and would need to be substantiated by formal investigation which is beyond the scope of this investigation into attentional bias.

The current experiments demonstrate that one way in which an attentional set can be immediately altered is through explicit knowledge of a task – i.e., an explicit information sheet, rather than an implicit inducement of bias such as sitting in a green room. While Kawahara (2010) was able to train participants to use a particular type of attentional set in the absence of explicit instructions, these did not amount to a stimulus-specific attentional control setting, just the selection of a general mode to search for stimulus features rather than rely purely on saliency (Kawahara, 2010; Leber, Kawahara, & Gabari, 2009). Moreover, in Kawahara (2010) and Leber et al. (2009), the training was a result of online trial-by-trial feedback using operant conditioning. A similar point was made by Hogarth & Duka (2006), however whereas they stressed the importance of explicit knowledge in the pairing of stimulus and reward, the current chapter provides substantial evidence that persistent, attentional control setting can be formed in the absence of reward.

This issue of reward raises an important point, since additional processing involving the mesolimbic dopamine reward system may well play an integral role in some observed attentional biases, such as addiction (Franken, 2003; Franken et al., 2005; Franken et al., 2004; Robinson & Berridge, 1993, 2008). Moreover, it has also been found that previously rewarding stimuli can reflexively capture attention when contextually irrelevant to a task (Anderson et al., 2011a, 2011b), and that such attentional capture by rewarding stimuli results in altered electrophysiological signatures of attentional selection (Kiss et al., 2009). It was argued that this value-driven capture develops via associative learning and has been likened to the way that irrelevant drug-related stimuli bias the attention of addicts (Anderson et al., 2011a). It is possible in session 1 of experiments 1, 2 and 3, and especially in Chapter 2 where participants had to reflect on their own accuracy, that participants were arbitrarily rewarded via improved accuracy on Congruent Change trials, especially considering the ratio of trial types. This subjective 'reward' could have reinforced the relevance of green items

causing them to continue to capture attention when task-irrelevant. However, value-driven capture is extinguished over many trials when consistently task-irrelevant (Anderson et al., 2011b). In the current experiments, the bias towards green items persists after two weeks with no re-exposure to the biasing information sheet and no requirement of participants to continuously evaluate their performance. Furthermore, the control experiment suggests that reward-based training has not occurred.

In summary, a single information sheet was used to induce a persistent attention control setting favouring the colour green in healthy participants in the absence of motivational processing relating to the evaluation of performance. This is synonymous with inducing an attentional bias towards the colour green. The bias was found to affect perceptual sensitivity to detect changes, which affected accuracy. This induced attentional bias was present outside the immediate testing situation – even when explicitly irrelevant to the task. This is the first time that a bias has been induced so quickly, and is so robust that it is present and affects behaviour in different settings a further two weeks later. This induced bias is mediated by a chronic change to attentional control settings that may involve long-term contextual learning. The current experiments build upon previous studies by highlighting the ease at which these changes to attentional control settings can occur and stress that the alterations to the point at which top-down information carries more weight than bottom-up information can be completely unconscious. Similar changes to attentional control settings may be a common factor in the attentional biases observed in various abnormal populations. Examining the effects of a pre-existing chronic alteration to attentional control settings on the inducement of a second may provide further information into the boundary limits of the ease of their establishment, how they are maintained, and how easy (or difficult) they are to disrupt once established.

Chapter 4

Effects of Inducing Attentional Bias in Light versus Heavy Social Drinkers

Overview

Previous chapters have found that an underlying mechanism of attentional bias is a persistent alteration of attentional control settings. However, it is unknown if already holding an attentional bias makes these control settings more prone to alterations. This has an impact on current studies of attentional biases, which focus on the relationship between attentional biases and pathologies such as addiction since people who already hold one attentional bias may be more susceptible to developing another. However due to the differences in neural functioning in many pathological groups, the sample populations used in these experiments make it difficult to apply findings to normative, non-addicted populations. This chapter compared an induced attentional bias towards an emotionally neutral feature (the colour green) in a sample of undergraduate heavy social drinkers with light social drinkers to investigate if a pre-existing bias makes it easier to procure a second attentional bias. It was found that both groups of social drinkers showed an equivalent biasing effect when green items were behaviourally relevant. However, light social drinkers were more distracted by the bias when a green item was present but irrelevant than heavy social drinkers. This may be due to heavy drinkers having more experience in exerting cognitive control over attentional biases. These findings demonstrate for the first time that an established attentional bias can have a distinct effect on the future allocation of visual attention and the ability of executive functioning to control for irrelevant distractions caused by irrelevant visual information.

4.1 Introduction

Chapters 2 and 3 examined the cognitive basis of attentional bias where it was found that a single information sheet is sufficient to create persistent bias towards an arbitrary visual stimulus in healthy individuals – indicating a cognitive mechanism underlying attentional bias. This cognitive mechanism may be a persistent alteration to an attentional control setting (Bacon & Egeth, 1994; Folk et al., 1992; Leber & Egeth, 2006a, 2006b). Chapter 3 expanded upon this, discovering that this bias could be induced in the absence of emotion or motivation, was sustained for at least two weeks and affected behaviour when both relevant and irrelevant to task demands. However, the potential relationship between a pre-existing persistent alteration of attentional control settings (a pre-existing attentional bias) and the procurement of an additional set of attentional control settings (the inducement of an attentional bias) has not yet been examined. This is important, since those who already possess an attentional bias also must already currently use the neural network involved in this bias. Knowing that it is possible to induce an attentional bias free from emotive or other aspects, this chapter therefore sought to examine attentional bias further by examining induced biases in a sub-clinical population who are already biased to an emotive stimulus.

Attentional bias is commonly studied in addiction (Field & Cox, 2008), where the development of addictive behaviours is consistently found to coincide with the development of an attentional bias towards addiction-related stimuli. Alcoholics show an attentional bias towards alcohol-related items, observed across various experimental paradigms including the Stroop (Lusher et al., 2004), dot-probe (Townshend & Duka, 2001) and flicker paradigms (Jones et al., 2003). Gambling addicts show a bias towards gambling-related items (Boyer & Dickerson, 2003), heroin addicts display a bias towards heroin-related items (Constantinou et al., 2010), smokers towards smoking-related items (Yaxley & Zwaan, 2005) and so on. Additionally, Cox, Hogan, Kristian and Race (2002) found that a reduction of alcohol-related attentional bias was related to success of treatment, 3 months following release from a rehabilitation centre. This suggests a causal, or at the very least, sustaining relationship between addiction and attentional bias, which is supported by more recent literature

(Flaudias et al., 2013). Furthermore, Stroop performance is related to the risk of treatment dropout in cocaine dependants (Streeter et al., 2008), highlighting the importance of examining the relationship between attentional bias and addictive behaviours.

Much of what is known about attentional bias stems from research comparing abnormal populations with healthy participants (Lusher et al., 2004; Noel et al., 2007; Sharma et al., 2001; Waters & Green, 2003). These have established that both alcohol dependents and those who abuse alcohol exhibit faster reaction times towards alcohol-related cues when task-relevant (Jones et al., 2006; Jones et al., 2003), and slower reaction times when alcohol-related cues interfere with task goals (Cox et al., 2000; Johnsen, Laberg, Cox, Vaksdal, & Hugdahl, 1994b). However, while these show how attentional bias manifests in addicted populations, many issues have yet to be resolved. Firstly as discussed in the General Introduction, the aforementioned paradigms can only *suggest* an attentional bias via differences in reaction time – by design, the paradigms do not allow for direct measurements of the allocation of attention. The paradigm developed and refined so far in this thesis overcomes this, since it is a more direct measurement of the deployment of attention that returns data on perceptual sensitivity and responder bias as well as reaction times. Secondly, inferences regarding attentional bias are mixed and sometimes inconsistent due to the examined populations. The use of alcoholics is flawed because of physical brain differences between addicts and the healthy population (Baler & Volkow, 2006; Cardenas, Studholme, Gazdzinski, Durazzo, & Meyerhoff, 2007; George, Potts, Kothman, Martin, & Mukundan, 2004; Goldstein & Volkow, 2011; Medina et al., 2008; Thompson et al., 2004). Long term abuse is related to a detrimental effect on the underlying brain structures relating to cognitive control and executive function (George et al., 2004; Goldstein & Volkow, 2011; Medina et al., 2008), such as the prefrontal cortex (PFC) (Crews & Boettiger, 2009; Cummings, 1993; Gruber, Silveri, & Yurgelun-Todd, 2007; Ratti, Bo, Giardini, & Soragna, 2002; Stuss & Alexander, 2000; Yurgelun-Todd, 2007; Yurgelun-Todd, Silveri, Gruber, Rohan, & Pimentel, 2007).

Chanraud, Pitel, Pfefferbaum & Sullivan (2011) observed compromised functional connectivity in the posterior cingulate (PCC) regions of alcoholics. Due to the extensive connectivity between the PCC and the fronto-pareital attention network (Leech, Kamourieh, Beckmann, & Sharp, 2011; Margulies et al., 2009; Vincent et al., 2006) – see Pages 33-34 in the General Introduction for an overview of this network – the PCC has been theorised to be involved in regulating attention (Hayden, Nair, McCoy, & Platt, 2008; Leech & Sharp, 2014; Mohanty, Gitelman, Small, & Mesulam, 2008). Regarding attentional bias, this suggests that the PCC may play a role in regulating attention either towards or away from bias-related information (Mohanty et al., 2008). In Chanraud et al. (2011), alcoholics and healthy social drinkers were scanned at rest and during a working memory task via fMRI (Chanraud, Pitel, Pfefferbaum, & Sullivan, 2011). At rest, the alcoholics displayed less synchronised slow fluctuations in the PCC and cerebellar regions, suggestive of lower efficiency. The alcoholics also displayed more robust connectivity between the left posterior and left cerebellar regions, despite performance in a recall task with differing interference and duration of levels being identical between the two groups. This suggests that the alcoholics not only had impaired functional connectivity, but may also have recruited additional compensatory networks to achieve a comparably normal working memory performance.

In addition, Cardenas et al. (2007) discovered that recovering alcoholics displayed a large amount of atrophy in the frontal and temporal lobes when initially entering treatment (Cardenas et al., 2007). This atrophy is partially reversible following total abstinence after 8 months, but is not present in alcoholics who relapse. Finally in a review, Baler & Volkow (2006) highlight that significant plastic adaptations occur in neurological circuits relating to – among others – salience attribution and inhibitory control (Baler & Volkow, 2006; Tremblay & Schultz, 1999; Volkow & Fowler, 2000), suggesting that the attribution of salience towards drug-related items in alcoholics may be influenced by these plastic changes that arise out of dopamine responses to reward. Such changes are not present in social drinkers (Chanraud et al., 2011; Desmond et al., 2003; Thompson et al., 2004; Yuan et al., 2009), thus in non-addicted samples, PFC function is not yet disrupted.

Disrupted PFC function in those who abuse substances is important, due to the established link between the PFC and higher level processes such as working memory, executive functioning and cognitive control (Adams et al., 1993; Crews & Boettiger, 2009; Cummings, 1993; Stuss & Alexander, 2000; Sullivan, Rosenbloom, & Pfefferbaum, 2000; Uekermann & Daum, 2008). Those with lowered executive functioning may therefore be more susceptible to developing addictions, due to the automatic associations formed with repeated presentations of stimulus and reward (Stewart, Dewit, & Eikelboom, 1984; Wise & Bozarth, 1987). These associations are then reinforced via dopamine responses to reward, which contributes to an increased saliency of reward-related items (Franken et al., 2005; Franken et al., 2004; Robinson & Berridge, 1993, 2004, 2008). Those with lowered executive functioning exert less control over processes triggered by these conditioned cues, leading to continued use and less success of treatment (Aharonovich et al., 2006). Baler and Volkow (2006) argue that through continued drug use and subsequent neurological alterations via dopamine responses, addicts can exert less self-control. Impaired decision making that arises as a result of this contributes significantly to the enduring nature of a variety of addictions (Baler & Volkow, 2006; Volkow & Fowler, 2000; Volkow, Fowler, & Wang, 2004; Volkow, Fowler, Wang, Baler, & Telang, 2009). Thus, differences in attention and attentional bias between abusers and healthy controls may be due to damage to essential neural networks caused by drugs of abuse, or due to poorer pre-existing executive functioning.

This link between reduced executive functioning and attentional biases feeds into the dual-process models of addictive behaviours fully discussed in Chapter 1 (Robinson & Berridge, 1993, 2000, 2008; Tiffany, 1990; Wiers et al., 2007). Despite their differences, all overviewed models stress the link between automatic and controlled processes in the development of addiction. Due to the effects of alcohol on the frontal lobes and the established link between the frontal lobes and executive functioning, these models suggest that those who abuse alcohol would be even less likely to exert cognitive control over their environment and would be even more susceptible to the development and behavioural effects of automatic processes. As stressed, attentional bias is an automatic process

(Bruce & Jones, 2006; Field & Cox, 2008) meaning that reduced executive regulation leads to a greater impact of attentional bias on behaviour. Furthermore, internally preventing a pre-potent response is believed to rely on executive functioning which cognitively controls behavioural responses (Groman, James, & Jentsch, 2009).

This concept is supported by many studies which have found that heavy drinkers have reduced working memory capacity, poorer decision making skills, exhibit more impulsive behaviour and have generally lower executive functioning than social drinkers (Adams et al., 1993; Perry & Carrol, 2008; Sullivan, Fama, Rosenbloom, & Pfefferbaum, 2002; Sullivan et al., 2000). Uekermann and Daum (2008) collated research across a 30 year period investigating the link between alcoholism and deficits in social cognition – thought to critically involve the PFC (Moselhy, Georgiou, & Kahn, 2001; Stuss, Gallup, & Alexander, 2001; Uekermann & Daum, 2008). They found a clear association between deficits in a range of social cognitions such as Theory of Mind and prosody perception (all of which involve the PFC) and alcoholism. This further supports the claim that prolonged alcohol abuse has a significant detrimental effect on the PFC, which is implicated in working memory and cognitive control (Fox et al., 2005).

A further issue is that across studies, age, educational attainment and working memory capacity are also inconsistent (Chanraud et al., 2011; Goldstein et al., 2004). These inconsistencies are even observed within studies. An example is Goldstein et al. (2004), who compared cocaine addicts with healthy controls, however the cocaine addicts had completed significantly fewer years of education and were also significantly more impaired on a battery of tests examining visual memory, verbal memory, attention and executive functioning. It is difficult to determine in this case if the differences between the two groups were due to the cocaine addiction or if the neuropsychological deficits came first – suggestive in the fewer years of completed education – followed by the addiction.

That is not to say that these population-specific concerns have been overlooked. Many studies have used more analogous samples such as comparisons of heavy and light social drinkers from university samples. Some studies have found group differences using Stroop tasks (Bruce & Jones, 2004; Fadardi & Cox, 2008). However, results are mixed with differences not always observed (Sharma et al., 2001). For example, while Sharma et al. (2001) found a Stroop effect in problem drinkers (where excessive drinking has a negative impact on day-to-day life) compared to heavy (where alcohol consumption does not impact day-to-day life) and light social drinkers, however there was no difference between the two groups of social drinkers. Consequently, research often focuses on individual differences. Field et al. (2011) investigated the link between alcohol consumption and an expectancy to receive alcohol in an eye-tracking task. Here, heavy and light social drinkers were informed of the probability of receiving an alcoholic drink following each trial. Heavy social drinkers displayed an attentional bias regardless of expectation (analysed via eye movements to alcohol-related cues), however only the 100% expectation condition produced this effect in light social drinkers.

Another study found that only social drinkers with high levels of alcohol craving showed evidence of increased approach towards alcohol-related cues in a dot probe task (Field, Mogg, & Bradley, 2005). These results suggest individual differences in subjective craving play a key role in alcohol-related attentional biases, but not necessarily in alcohol consumption levels for social drinkers. Finally, alcohol preload before testing increases attentional bias towards both alcohol- (Jones & Schulze, 2000; Schoenmakers, Wiers, & Field, 2008) and cocaine-related items (Montgomery et al., 2010). Similar results were found when participants were primed by an alcoholic or placebo drink, then asked to perform an Eriksen Flanker task superimposed on either a neutral or alcohol-related background, while being scanned via fMRI (Nikolaou et al., 2013). While a high dose of alcohol reduced overall neural activity (and activity in both medial and dorsal PFCs), a low dose of alcohol increased latency when the flanker task was completed on alcohol-related backgrounds, suggesting it had caused an increase in alcohol-related attentional bias.

The group differences observed only after experimental manipulation or via individual differences suggest that these previous investigations (and the chosen methodologies) are not sensitive enough to detect group differences in attentional bias between non-clinical heavy and light social drinkers. However, it must be noted that more success has been found via the dot probe paradigm (Field et al., 2004; Townshend & Duka, 2001), which is arguably a more suitable paradigm to examine early attentional capture than the Stroop or Dual Task paradigms. Nevertheless as discussed in the General Introduction, the Dot Probe task is still not a wholly direct measurement of initial attentional orienting, though it does suggest that heavy social drinkers have an increased alcohol-related attentional bias over light social drinkers.

Based on the link between frontal lobe functioning and the executive control of attention, it seems likely that inducing an additional attentional bias in a population who already hold a bias compared to one who does not will have differential effects – even when levels of executive functioning are controlled for. Since those with an attentional bias already use the neurological pathways used to create and maintain the attentional control settings relating to their bias, it is possible that here, it will be easier to further alter or manipulate these settings (Banich et al., 2000; Garavan, Ross, Murphy, Roche, & Stein, 2002; Luks, Simpson, Dale, & Hough, 2007). This would mean that those with a pre-existing attentional bias would be more susceptible to the procurement of a second and would display behavioural evidence of an additional bias in a more extreme way. However, a more likely option is that alterations to attentional control settings may be rigid and difficult to interfere with. In this case, it would be more difficult to induce a second attentional bias in a population who already hold one, and this population would demonstrate less extreme behavioural effects of a second induced bias. A final possibility is that those who already hold a bias may already have experience in cognitively controlling for their bias. This possibility would mean that those with practice exerting control over attentional bias-related items may be more successful at ignoring bias-related items when they become task-irrelevant.

This current study extends the findings of Chapter 3 to discover if it is easier to alter attentional control settings in heavy social drinkers who already have persistently altered settings, than light social drinkers who do not. This will be measured via changes to perceptual sensitivity caused by the reading of an information sheet prior to testing in a two tasks where items relating to the information sheet are either behaviourally relevant or irrelevant. The latter task will also enable the investigation of how distracted heavy and light social drinkers are by induced, arbitrary biases. Due to the use of a pre-clinical sample of heavy versus light social drinkers, this study will also be free of the methodological issues discussed regarding the use of addicted populations. Furthermore, it will be assumed that all participants will have similar working memory capacity and executive functioning, since they are undergraduate students at a leading UK university, who have all completed at least 14 years of education, allowing for more reliable inferences to be drawn about attentional bias.

4.2 Assessment of Attentional Bias to Alcohol

4.2.1 Method

4.2.1.1 Participants

Initially, 124 (33 male) undergraduate students in their first or second year of an Applied Psychology course at Durham University aged 18-37 (M: 20.20, SD 3.33) completed an alcohol consumption questionnaire (Time Line Follow Back (Sobell & Sobell, 1992)) in order to obtain samples of heavy and light social drinkers. Smoking and/or the taking or recreational drugs were exclusion criterion. Of these, 50 participants (12 male), aged 18-22 (M: 20.08, SD: 1.59) with normal or corrected to normal vision and no colour blindness took part. The sample consisted of 25 heavy and 25 light social drinkers. Heavy social drinkers had an average weekly consumption of 56.86 units (SD: 21.41), light social drinkers had an average weekly consumption of 7.98 units (SD: 4.25). These differed significantly: $t(48) = -11.196$, $p<.001$, $r = .8504$. All participants gave their informed consent with the approval of Durham University Ethics Advisory Committee and were provided with participant pool credits for their time.

4.2.1.2 Apparatus

All experimental stimuli were programmed in C++ using Borland C++ builder and produced via a ViSaGe box and custom graphics card (Cambridge Research Systems, Rochester, England). They were displayed using a 19" Sony Triniton monitor with a resolution of 1024x768 and a refresh rate of 100Hz. Responses were collected via a custom-made parallel-port two-button button box.

4.2.1.3 Stimuli & Procedure

A white fixation cross situated in the center of a black screen (0.7° x 0.7° visual angle) was presented for 1000ms, followed by a square test array (visual angle: 10.2° x 10.2°) comprising four different images of either alcohol-related or neutral images (visual angle: 2.5° x 2.5°) for 750ms. This was masked via a blank screen for 100ms before reappearing. Stimuli remained present until a response was made. On 20% of trials, all images were originally alcohol-related and one changed into a different alcohol-related image (Alcohol-Alcohol Trials), on 20% of trials all images were originally alcohol-related and one changed into a neutral image (Alcohol-Neutral Trials), on 20% of trials all images were originally neutral and one changed into an alcohol-related image (Neutral-Alcohol Trials), on 20% of trials all images were originally neutral and one changed into a neutral image (Neutral-Neutral Trials). On the final 20% of trials no change occurred (No Change Trials). There were 225 trials in total split into three blocks. Participants were asked to detect a change as quickly as possible. See Figure 4.1 for an illustration of a typical trial.

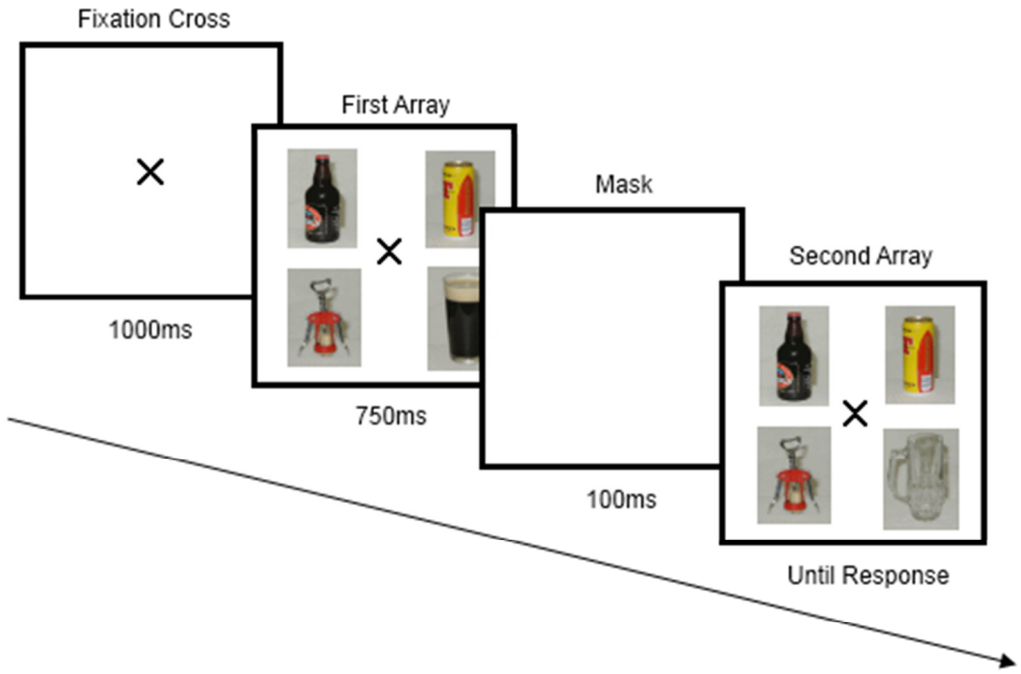

Figure 4.1: **Typical Alcohol-Alcohol trial in the Alcohol Change Detection task.** A fixation cross is presented for 1000ms followed by the first array for 750ms. This is then masked for 100ms before reappearing until participants make a response.

4.2.2 Results

Sensitivity measured via d' was entered into a 2 (Drinker: Heavy/Light) x 4 (Trial Type: Alcohol-Alcohol/Alcohol-Neutral/Neutral-Alcohol/Neutral-Neutral) mixed factor ANOVA. Trial was a within subjects factor, Drinker was a between subjects factor. There was no main effect of drinker ($F(1,48) = 1.759$, $p = .191$, $r = .188$), however Trial Type and Drinker interacted: $F(3,144) = 10.032$, $p < .001$, $r = .254$. Independent t-tests comparing Heavy versus Light drinkers for each trial type revealed a significant difference in Neutral-Alcohol trials: $t(48) = -3.263$, $p < .01$, $r = .426$. Here, d' scores of heavy drinkers was higher by an average of .4326 as shown in Figure 4.2.

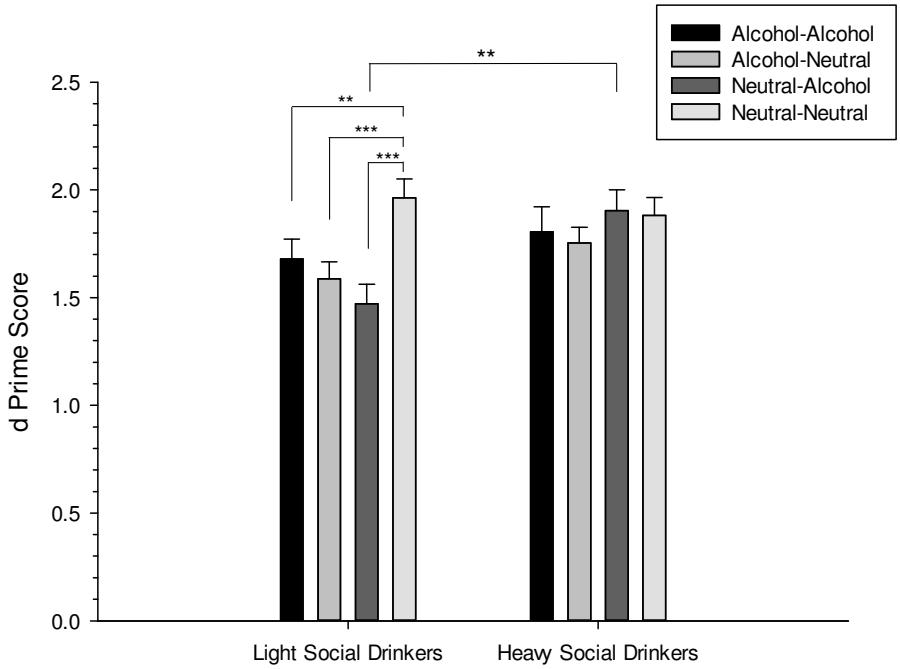

Figure 4.2: **Pre-existing alcohol-related attentional bias in light versus heavy social drinkers.** Higher d' indicates increased sensitivity to change. Sensitivity is higher in heavy social drinkers than light social drinkers when an alcohol-related image appears amongst neutral images. For light social drinkers, sensitivity is highest when a novel neutral image appears amongst other neutral images. Error bars show standard error of the mean. *Note:* ** p<.005, *** p<.001

4.2.3 Interim Discussion

Heavy social drinkers display a pre-existing attentional bias towards alcohol-related items over light social drinkers, as supported by previous studies (Field et al., 2004; Jones et al., 2003; Townshend & Duka, 2001). This attentional bias manifests in heavy social drinkers' increased perceptual sensitivity at detecting when a novel alcohol-related item appeared amongst previously neutral items. Heavy drinkers' attention was captured by the novel alcohol-related item, increasing their sensitivity to accurately detect the alcohol-related item's appearance and thus suggesting a pre-existing alcohol-related attentional bias. This increase in sensitivity was not observed in light social drinkers, suggesting no alcohol-related attentional bias in our light social drinkers. Therefore, we can conclude that our participant samples to investigate the effect of a pre-existing attentional bias on the procurement of a second attentional bias are valid.

4.3 Attentional Bias Inducement Task

4.3.1 Method

4.3.1.1 Participants & Design

Participants were the same as those used for the alcohol change detection task and were tested in the same experimental session. Thus, once participants were recruited for the experiment following the completion of the alcohol consumption questionnaire, they completed first the alcohol change detection task, followed by the attentional bias inducement task during the same experimental session. A mixed design was used. Following the completion of the alcohol attentional bias experiment, all participants carried out the colour change detection task however this included separate groups of heavy and light social drinkers.

4.3.1.2 Apparatus, Stimuli & Procedure

Apparatus, stimuli and procedure were identical to Experiment 1 of Chapter 3 (pages 79-81).

4.3.1.3 Statistical Analyses

Accuracy, d' scores offering a measurement of perceptual sensitivity, and criterion scores offering a measurement of responder bias (the propensity to report more changes or no changes) were analysed. Several Mixed Factor ANOVAs were completed. In all primary and subsequent analyses, Bonferroni corrections for multiple comparisons were applied.

4.3.2 Results

Outliers with a reaction time above or below 2 standard deviations from the mean were excluded from analyses, resulting in the loss of 0.35% of trials.

4.3.2.1 Accuracy

Accuracy was entered into a 2 (Drinker: Heavy/Light) x 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) mixed factor ANOVA. Trial was a within subjects factor, Drinker was a between subjects factor.

There was a main effect of Trial: $F(2,96) = 53.330$, $p<.001$, $r = .592$. Accuracy in Congruent Change trials was significantly higher (M: .888) than accuracy in Incongruent (M: .706, $p<.001$, $r = .752$) and

Neutral Change trials (M: .728, p<.001, r = .756). Accuracy in Neutral and Incongruent Change trials did not differ (p = .099, r = .236). There was also a main effect of Drinker: F(1, 48) = 5.053, p = .029, r = .309. Overall, heavy social drinkers were more accurate (M: .802) than light social drinkers (M: .746) by an average of 5.6%. Finally, there was a marginal interaction between Trial and Drinker: F(2, 96) = 2.848, p = .063, r = .170. This was further investigated via two one-way ANOVAs investigating the effect of each Type of Trial on accuracy separately for Heavy and Light social drinkers.

The ANOVA for Light social drinkers was significant: F(2, 48) = 37.033, p<.001, r = .668. Accuracy in Congruent Change trials was significantly higher (M: .883) than accuracy in Incongruent (M: .655, p<.001, r = .802) and Neutral Change trials (M: .700, p<.001, r = .803). Accuracy in Neutral Change trials was also significantly higher than accuracy in Incongruent Change trials (p = .031, r = .423). The ANOVA for Heavy social drinkers was also significant: F(2, 48) = 17.909, p<.001, r = .521. Accuracy in Congruent Change trials was significantly higher (M: .892) than accuracy in Incongruent (M: .756, p<.001, r = .676) and Neutral Change trials (M: .756, p<.001, r = .697). Accuracy in Neutral and Incongruent Change trials did not differ (p = .999, r = .001).

4.3.2.2 d'

d' was entered into a 2 (Drinker: Heavy/Light) x 3 (Trial Type: Congruent Change/Incongruent Change/Neutral Change) mixed factor ANOVA. There was a significant effect of Trial: F(2,96) = 11.848, p < .001, r = .332. As Figure 4.3 shows, d' scores in Congruent Change trials were higher than Incongruent Change trials (mean difference .760, p<.001, r = .783) and Neutral Change trials (mean difference .702, p = .003, r = .454). Thus, participants were more sensitive to detecting changes to green stimuli than other stimuli, suggesting a successful induced bias towards the colour green. There was no effect of Drinker: F(1,48) = .812, p = .372, r = .129, and no interaction between Trial and Drinker: F(2,96) = .237, p = .770, r = .081.

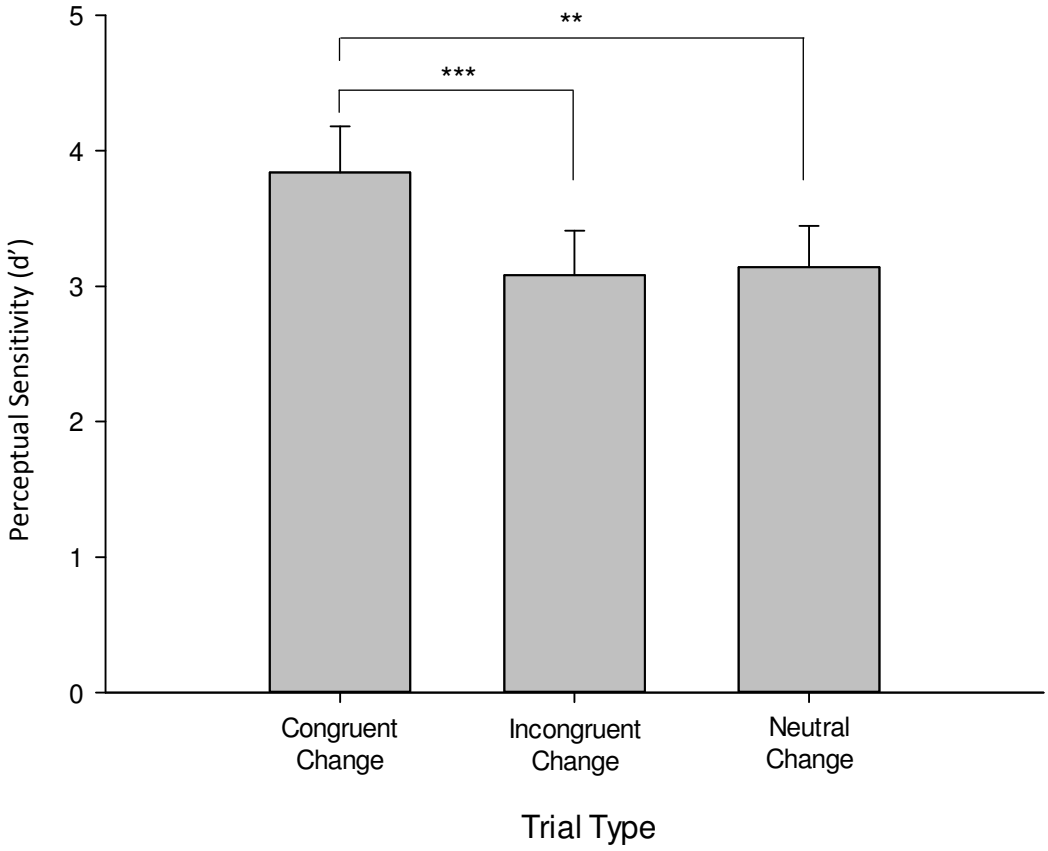

Figure 4.3: **Effect of induced attentional bias towards green on d' in a change detection task.** Higher d' indicates greater sensitivity to change. Sensitivity is higher in Congruent Change trials than both Incongruent and Neutral change trials. This difference is larger in Congruent compared to Incongruent Change trials, thus attention is captured by a biased stimulus, and it also distracts from detecting other changes. Error bars show standard error of the mean. *Note:* ** p<.005, *** p<.001

4.3.2.3 Criterion

Criterion scores were entered into a 2 (Drinker: Heavy/Light) x 3 (Trial Type: Congruent Change/Incongruent Change/Neutral Change) mixed factor ANOVA. Drinker was a between subjects factor, Trial was a within subjects factor. There was a main effect of Trial: $F(2, 96) = 3.532$, $p = .040$, $r = .184$. Criterion scores of Congruent Change trials were significantly lower (M: .876) than Criterion scores of Incongruent Change trials (M: 1.227, $p<.001$, $r = .728$). Criterion scores of Neutral Change trials were also significantly lower (M: .885) than Criterion scores of Incongruent Change trials ($p = .045$, $r = .372$). There was no difference between the Criterion scores of Congruent compared to Neutral Change trials ($p = .961$, $r = .011$). There was no effect of Drinker: $F(1,48) = 2.371$, $p = .141$, $r = .217$, and no interaction between Trial and Drinker: $F(2,96) = .361$, $p = .699$, $r = .099$.

4.3.3 Interim Discussion

This experiment investigated if a pre-existing attentional bias affected the procurement of an additional bias by examining if heavy social drinkers are more easily biased towards a neutral stimulus than light social drinkers. Evidence was found of an equally successful inducement of an attentional bias towards the colour green in both heavy and light social drinkers. Both groups showed an increase in sensitivity at detecting changes to green stimuli, with a larger effect size between sensitivity of detecting congruent and incongruent trials than congruent and neutral trials. If those with a pre-existing attentional bias were more receptive at having additional biases induced, we would expect to see greater sensitivity at detecting green changes in heavy social drinkers compared to light social drinkers. However, our results from heavy and light social drinkers did not differ, thus we can conclude that having a pre-existing attentional bias does not alter the extent to which an arbitrary bias is induced. However, the results do suggest that there may be a difference in how distracted heavy and light social drinkers are by bias-related information when it is irrelevant to a particular task. Accuracy results showed that only in light social drinkers was there a detrimental effect of the presence of a green item when a different item changed colour (Incongruent Change trials). However, when calculating perceptual sensitivity, this effect was no longer present. The potential differences in distractibility will therefore be investigated more thoroughly in a shape change detection task.

4.4 Distractibility from an Induced Attentional Bias

4.4.1 Method

4.4.1.1 Participants & Design

This experiment took place immediately following the alcohol attentional bias task and the attentional bias inducement task. Consequently, participants and design were the same as those used for the attentional bias inducement task. However, instead of detecting changes to colours, participants were asked to detect changes between presented arrays of shapes.

4.4.1.2 Apparatus, Stimuli & Procedure

Apparatus, stimuli and procedure were identical to Experiment 2 of Chapter 3 (pages 89-91).

4.4.1.2 Statistical Analyses

Accuracy, d' and criterion scores were analysed. These were entered into several mixed factor ANOVAs. In all analyses, Bonferroni corrections for multiple comparisons were applied.

4.4.2 Results

4.4.2.1 Accuracy

Accuracy was also entered into a 2 (Drinker: Heavy/Light) x 2 (Bias: Green Present/Green Absent) x 2 (Trial: Change/No Change) mixed factor ANOVA. Drinker was a between subjects factor, Bias and Trial were within subjects factors. There was no main effect of Drinker: $F(1,48) = 1.686$, $p = .200$, $r = .182$. As expected, there was a main effect of Trial: $F(1, 48) = 60.969$, $p<.001$, $r = .748$. Accuracy in No Change trials was significantly higher (M: .871) than accuracy in Change trials (M: .695). There was also a main effect of Bias: $F(1,48) = 15.889$, $p<.001$, $r = .499$. Accuracy in Bias Present trials was significantly lower (M: .768) than Bias Absent trials (M: .798). Bias and Trial also interacted: $F(1,48) = 26.278$, $p<.001$, $r = .594$. A series of paired-samples t-tests were conducted between each Trial type in each Bias condition. Accuracy in Green Absent Change trials was significantly higher than Green Present Change trials (Green Present Change – Green Absent Change: $t(49) = 4.939$, $p<.001$, $r = .577$). However, accuracy in Green Present No Change trials was significantly lower than accuracy in Green Absent No Change trials (Green Present No Change – Green Absent No Change: $t(49) = -3.024$, $p = .004$, $r = .397$).

Bias and Drinker interacted: $F(1,48) = 6.875$, $p = .012$, $r = .354$. Two independent samples t-tests comparing the accuracy of Green Present trials, and Green Absent trials for Heavy and Light drinkers revealed no difference in accuracy in Heavy compared to Light social drinkers in Green Present trials: $t(98) = 1.258$, $p = .212$, $r = .179$. Likewise, there was no difference in accuracy between Heavy and Light social drinkers in Green Absent Change trials: $t(98) = .169$, $p = .866$, $r = .024$. The interaction in this instance most likely relates to the differences in effect sizes between the two analyses, since

both analyses revealed no significant differences. Trial and Drinker also interacted: $F(1,48) = 6.158$, $p = .017$, $r = .337$. Two independent samples t-tests were conducted comparing the accuracy of Change trials in Heavy and Light social drinkers, and the accuracy of No Change trials in Heavy and Light social drinkers. The t-test for Change trials was significant: $t(98) = 2.776$, $p = .007$, $r = .372$. Here, Heavy social drinkers were significant more accurate (M: .735) than Light social drinkers (M: .655). The t-test for No Change trials revealed no significant difference in accuracy between Heavy and Light social drinkers: $t(98) = 1.857$, p - .067, $r = .259$.

Finally, there was a significant three-way interaction between Bias, Trial and Drinker: $F(1,48) = 4.553$, $p = .038$, $r = .294$. This was investigated via two repeated-measures ANOVAs investigating the interaction between Bias and Trial separately for Heavy and Light social drinkers. The ANOVA for Light social drinkers showed a main effect of Bias: $F(1,24) = 15.059$, $p = .001$., $r = .621$. Green Absent trials were detected significantly more accurately than Green Present trials (mean difference: .050). There was a main effect of Trial: $F(1,24) = 54.114$, $p<.001$, $r = .832$. As expected, No Change trials were detected more accurately than Change trials (mean difference: .232). Finally, there was an interaction between Bias and Trial: $F(1,24) = 15.619$, $p = .001$, $r = .628$. This was investigated via a series of paired-samples t-tests comparing each type of trial. All were significantly different from each other, including the two types of No Change trials: $t(24) = 2.295$, $p = .031$, $r = .424$, where Green Present No Change trials were detected significantly more accurately than Green Absent No Change trials. This suggests light social drinkers were distracted by the presence of a green shape, since its presence caused an increase in No Change responses. As green shapes never changed shape, this suggests attention was captured by this non change, resulting in the observed increase.

The repeated measures ANOVA for Heavy social drinkers however yielded no main effect of Bias: $F(1,24) = 1.691$, $p = .206$, $r = .257$. There was a significant main effect of Trial: $F(1,24) = 13.866$, $p = .001$, $r = .605$ where, as expected, No Change trials were detected significantly more accurately than Change trials. There was also a significant interaction between Bias and Trial: $F(1,24) = 14.318$, $p =$

.001, r = .611. Again, a series of paired-sample t-tests were conducted which were all significant but for the t-test comparing the two types of No Change trials: t(24) = 1.932, p = .065, r = .367. Thus for heavy drinkers, there was no difference in the amount of false positives reported in the two types of No Change trials. These results suggest that the induced attentional bias had a greater impact on light social drinkers than on heavy social drinkers, even though both groups showed behavioural evidence of an induced attentional bias.

4.4.2.2 d'

d' was entered into a 2 (Drinker: Heavy/Light) x 2 (Trial Type: Green Present Change/Green Absent Change) mixed factor ANOVA. Drinker was a between subjects factor, Trial was a within subjects factor. There was a main effect of Trial Type: F(1,48) = 8.211, p =.006, r = .389. Participants had a significantly higher d' when there was no green shape present (mean difference 0.187 ± 0.065). There was also an interaction between Trial Type and Drinker: F(1,48) = 7.780, p = .008, r = .374. Two independent t-tests comparing heavy and light drinkers for both Trial types were conducted. There was no difference between drinker groups for Green Absent trials: t(48) = .189, p = .851, r = .027, however there was a significant difference between groups in Green Present trials: t(48) = -2.154, p = .036, r = .296. Light drinkers had lower d' scores in Green Present change trials (M: 1.488) than heavy social drinkers (M: 1.821), as shown in Fig. 4.4.

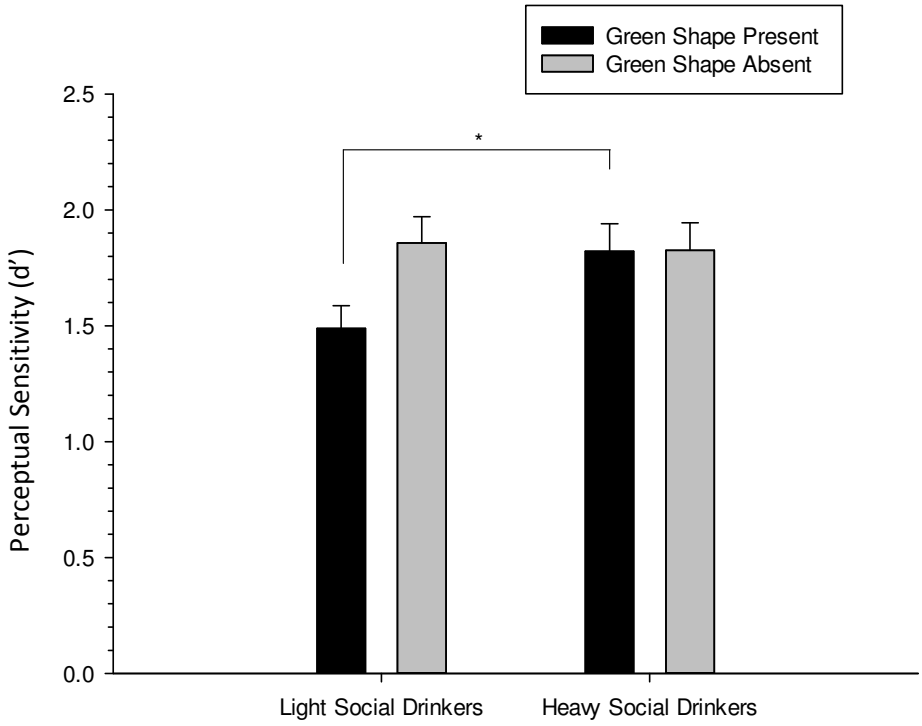

Figure 4.4: Effect of the presence of a biased stimulus (a green shape) on d' when colour is task-irrelevant. Lower d' indicates decreased sensitivity to change. Light social drinkers are less sensitive at detecting changes when a green shape is present than heavy social drinkers. This suggests light social drinkers are more distracted by the green shape – since it never changes – than heavy social drinkers. *Note*: * p<.05

4.4.2.3 Criterion

Calculated Criterion scores were also entered into a 2 (Drinker: Heavy/Light) x 2 (Trial Type: Green Present Change/Green Absent Change) mixed factor ANOVA. Drinker was a between subjects factor, Trial was a within subjects factor. There was a main effect of Drinker: $F(1, 48) = 6.614$, $p = .013$, $r = .348$. Criterion scores of Light social drinkers was significantly higher (M: .451) than Criterion scores of Heavy social drinkers (M: .175). Since a higher Criterion indicates an increase in the conservativeness of responses (more likely to report No Changes), this suggests that Heavy social drinkers are more liberal with their responses than Light social drinkers. There was also a significant main effect of Trial: $F(1, 48) = 14.299$, $p<.001$, $r = .749$. Criterion scores in Green Present Change trials was significantly higher (M: .412) than Criterion scores in Green Absent Change trials (M: .215). Thus, participants are more conservative with their responses when a green shape is present.

4.4.3 Interim Discussion

Following an induced attentional bias towards green items, light social drinkers - who had no pre-existing attentional bias – were more distracted away from detecting changes to shapes when a green shape was also present, whereas heavy social drinkers - who had a pre-existing alcohol-related attentional bias - were not. This distraction in light social drinkers manifested in lower perceptual sensitivity to detect changes - estimated with d' - when an irrelevant green shape was also present. This reduction in perceptual sensitivity had an effect on accuracy when a green shape was also present in an array. Thus, light social drinkers are more distracted by induced non-emotional attentional biases than heavy social drinkers.

4.5 Discussion

This series of experiments expanded previous findings by examining the effects of a pre-existing attentional bias on the ease of altering attentional control settings to induce a new additional bias. No group differences in perceptual sensitivity on initial attentional bias inducement were found, meaning that those with a pre-existing attentional bias do not appear to have more easily alterable attentional control settings. However, having a pre-existing attentional bias did have an effect on how distracted participants are when presented with task-irrelevant bias-related items. Light social drinkers were significantly more distracted from the primary task goal than heavy social drinkers when bias-related items were present but irrelevant. This suggests that a pre-existing attentional bias actually makes participants more successful at ignoring items they have previously attended to. Thus, while it is equally possible to induce an attentional bias in both heavy and light social drinkers, those who already hold an attentional bias to drinking related items show the effects of the induced bias in a less extreme way, as it does not distract when it becomes irrelevant.

Since the two groups in this study differed only in their alcohol-consumption levels, and as such on their pre-existing attentional biases, one explanation is that heavy drinkers are more practiced at controlling for attentional biases. In this experiment, heavy social drinkers (six of whom drank more than three times the NHS recommended weekly intake of alcohol of 2-3 units daily for women; 3-4

units daily for men) already hold an attentional bias towards alcohol which they have to control on a day-to-day basis. These control mechanisms may then utilised in the shape (distraction) change detection task meaning that the heavy social drinkers are more prepared to control for distractions caused by a further induced bias. Since light social drinkers have no pre-existing attentional bias to control for in the first place (and displayed no such bias in the alcohol change detection task), no control mechanisms exist, causing increased distractions by the induced green-related bias.

This explanation of the current findings is supported by a study from Hester and Garvan (2009) who examined cocaine-related attentional bias in conjunction with fMRI. In this study, cocaine users and non-users completed a series of tasks on either a neutral or cocaine-related background. Cocaine users who showed lower levels of distraction by cocaine-related items had increased activity in the right PFC, suggesting they were exerting higher amounts of cognitive control when completing the experimental task on a cocaine-related background. While caution must be made when drawing conclusions from this study due to the issues surrounding the use of substance dependent participants, this study does highlight the role of the PFC in controlling for irrelevant distractors; at least in addicted populations.

Despite the different experimental populations between Hester and Garavan's study compared to those examined in this chapter, it is probable that since our heavy and light social drinkers are all undergraduate students at a top-ranking university in the UK (Education, 2012), the participants used in the current experiments all use regularly exercise their PFC to match the demands of their studies (Ostlund & Balleine, 2005; Prabhakaran, Narayanan, Zhao, & Gabrieli, 2000; Ramnani & Owen, 2004; Winocur & Moscovitch, 1990). Consequently, pre-clinical samples of individuals with heightened or well exercised PFC function such as highly educated adults or adolescents in further education (Duncan et al., 2000; Geake & Hansen, 2005; Gordon et al., 2008; St Clair-Thompson & Gathercole, 2006) arguably have even greater reflective control over reflexive processes. Hence, it is possible that the cognitive control utilised by the heavy drinkers in the current study may only be

present in well-educated heavy drinkers with advanced PFC function (Alloway & Alloway, 2010; Blair, Gamson, Thorne, & Baker, 2005). Such a situation is problematic for previous investigations of attentional bias since a large amount of research use either convenience samples of university students and attribute findings to chronic abuse patients (Hallgren & McCrady, 2013; Montgomery et al., 2010; Townshend & Duka, 2001), or use addicted individuals in treatment programs (Connolly, Foxe, Nierenberg, Shpaner, & Garavan, 2012; George et al., 2004; Goldstein et al., 2004; Goldstein et al., 2001), many of whom have completed fewer years of education.

Furthermore, the increased severity of alcohol-related attentional biases in long-term compared to short-term alcoholic patients disappears when the cognitive functioning of patients is controlled for (Loeber, Vollstadt-Klein, et al., 2009). Due to the link between long-term abuse and atrophy of prefrontal regions (George et al., 2004; Goldstein & Volkow, 2011; Ratti et al., 2002; Yurgelun-Todd et al., 2007), this could also be explained in terms of reduced prefrontal functioning of chronic abuse patients – an issue that the current experiment overcomes. In Goldstein et al. (2004), both groups of addicts tested had significantly fewer years of education than the control group, and were significantly more impaired on measurements of executive functioning. The number of years of education of these experimental groups may have been directly related to their executive functioning. Alternatively, the use of addicted populations could also play a role in the observed behavioural differences between the addicts and controls, since long term abuse has a detrimental effect on the brain regions relating to cognitive control and executive function (Desmond et al., 2003; George et al., 2004; Medina et al., 2008; Thompson et al., 2004). The use of pre-clinical heavy drinkers in the current study (comparable drinkers along the alcohol use/misuse/abuse spectrum but who do not abuse alcohol) has overcome this issue. This has allowed for a clearer examination of the development and control of attentional bias in young adults.

The differences in testing populations between the current experiment and previous explorations of attentional bias could also explain why some previous research has found that heavy drinkers can exert less cognitive control over their environment. Noël et al. (2007) found that alcoholics not only exhibit deficits in response inhibition, but that these deficits are enhanced when trying to suppress something alcohol-related (Noel et al., 2007). Response inhibition can be defined as an internal prevention of a pre-potent behaviour (Groman et al., 2009; Monterosso et al., 2005), and as such is also thought to rely on executive functioning which cognitively controls the automatic behaviour (Goldstein et al., 2001; Groman et al., 2009). This therefore suggests that even when dealing with non-alcohol-related stimuli, Noel et al.'s sample of alcoholics had reduced executive functioning resulting in lower cognitive control over behaviour. The current experiment shows that heavy social drinkers are able to exert a large amount of cognitive control; however, this again could be related to the testing populations and offers more support that cognitive control over distractions caused by attentional biases may only be present in those with high functioning PFCs.

On the other hand, the addiction literature has suggested that the mesolimbic dopamine response elicited by drug-related stimuli can cause drug-related stimuli to capture attention (Franken, 2003), making it critical to the efficacy of addiction-related attentional biases. Montgomery et al. (Montgomery et al., 2010) examined this link further by administering a low dose of alcohol to groups of cocaine users and non-users. Alcohol preload in cocaine users increased participants' cocaine-related attentional bias. It was argued that the alcohol preload caused a mesolimbic dopamine response which raised the incentive salience of cocaine-related items, causing them to capture attention (Robinson & Berridge, 1993). While alcohol can also impair inhibitory control (Loeber & Duka, 2009a, 2009b; Loeber, Duka, et al., 2009), the fact that the alcohol preload had no effect in non-users suggests that the effect in cocaine-users was not due to such an impairment, and was instead due instead to an increase in internally-modulated salience. This incentive salience is only present in cocaine-users due to the many pairings of stimulus and reward that occur alongside use. Crucially, Franken (Franken, 2003) suggests that even alcohol-related cues can elicit a dopamine

response which will cause an increase in the incentive salience of stimuli (see Pages 27-28 of this thesis for an overview of this concept). However, this theory of a dopamine response does not explain the findings in this chapter.

In the current experiment, all participants received the alcohol change-detection task to analyse their alcohol-related attentional bias (which presented alcohol-related stimuli) before all other change detection tasks. This should have elicited a dopamine response in both heavy and light social drinkers. This dopamine response would have raised the incentive salience towards green items for all participants, since in the colour change detection task it is behaviourally advantageous (and motivationally reinforced) to attend to green. Crucially, this response should have been magnified in the heavy social drinkers, since they preferentially attended to the alcohol-related images in the task more than the light social drinkers (evidenced in heavy drinkers' increased perceptual sensitivity in Neutral-Alcohol trials). An increase in incentive salience in heavy social drinkers should therefore have resulted in an increased attentional bias towards the green stimuli in both the colour and the shape change detection tasks, which did not occur. No difference in perceptual sensitivity towards green stimuli was found between heavy and light social drinkers in the colour change detection task. Furthermore, there was evidence of a greater attentional bias in light social drinkers in the shape task, since they were more distracted by green items when they were irrelevant. This suggests that heavy social drinkers did not have increased incentive salience towards green items caused by a dopamine response to the alcohol-related images in the alcohol change detection task. Thus, a dopamine response and resulting incentive salience is not a prerequisite for an attentional bias to form (though whether it can reinforce a pre-existing bias remains to be tested). However, this discrepancy could also again be related to testing populations. Heavy social drinkers in the current task had highly exercised prefrontal cortices and were therefore more able to control for overall increases in attentional biases than the cocaine users used in Montgomery et al. (2010) since cocaine use is related to deficits in frontal regions (Hester & Garavan, 2004; Montgomery et al., 2010).

An alternative explanation of the current findings relates to the rigidity of stimulus-specific attentional control settings once established. In the colour change detection task, attending to green objects was behaviourally relevant and advantageous, since changes occurred to green objects 25% of the time. However, attending to colour (especially green) was behaviourally disadvantageous in the shape task. Since a key aspect of attentional bias is that bias-related items interfere even when task-irrelevant, behaviour in the shape task is a good indication of the presence (and persistence) of an attentional bias. As emphasised, light social drinkers show the effects of the induced bias in the shape task to a greater extent than heavy social drinkers. This suggests that heavy social drinkers are only biased towards green objects when they are behaviourally relevant. When they are explicitly irrelevant, It is possible that there is an attempt to cancel the alterations to the attentional setting that is driving the bias (Bacon & Egeth, 1994; Leber & Egeth, 2006a, 2006b). However, this would imply a conscious effort on behalf of the observer to change the attentional control setting. A more likely explanation is that once attentional control settings have been altered towards one type of visual feature – as they are in heavy social drinkers for their pre-existing alcohol-related attentional bias – these are very difficult to alter or interfere with. Thus, the neural networks involved in initially establishing a stimulus-specific attentional control setting are easily formed, but once created are difficult to manipulate. This may be related to the dopamine hypothesis previously discussed. It is possible that the numerous dopamine responses triggered in day-to-day life (particularly those relating to substances which also result in a dopamine response such as alcohol) continuously raise the incentive salience of whatever items match a pre-existing attentional control setting. This reinforces the setting, making it less likely that it can be interfered with and that an alternative setting can be formed and kept active.

This possibility is also supported by findings from the addiction literature that have tried to experimentally manipulate attentional biases. Field et al. (2007) found that heavy drinkers' alcohol attentional bias can be increased by experimental manipulation, and that this increase generalises to alcohol-related stimuli not originally used in the manipulation paradigm. However, manipulating

heavy drinkers to avoid alcohol-related items was met with limited success that did not generalise – a finding supported by other studies. These include other studies involving alcohol re-training (Schoenmakers et al., 2007), tobacco re-training (Field, Duka, Tyler, & Schoenmakers, 2009) and threat-related re-training (Van Bockstaele, Koster, Verschuere, Crombez, & De Houwer, 2012). Again, this suggests that the neural network involved in attentional bias can only be altered by attempts to reinforce what is already present. Trying to establish conflicting control settings that are incongruent to previously established settings is met with little success.

On the other hand, the limited success of attentional re-training may be explained by emotional connections to particular stimuli. It is possible that the highly-emotive content of addiction-related attentional biases may make these biases more robust – potentially via an emotionally-triggered dopamine response (Janes et al., 2010). Alternatively, the lack of success of re-training tasks may be due to the nature of tasks used as these typically use differential probabilities of probes replacing non- bias-related images in dot-probe tasks that implicitly re-train participants (Schoenmakers et al., 2007), whereas evidence suggests that attentional biases must be formed by explicit links (Hogarth & Duka, 2006). However, the present findings suggest instead that this could be because of the highly-robust nature of persistently altered attentional control settings and as such, of attentional biases. Furthermore, contextual environmental cuing of these attentional control settings (Cosman & Vecera, 2013) could further exacerbate the difficulties in manipulating them.

The present chapter also expands the findings from Chapter 3 by discovering sub-group differences in the overall induced bias effect. When the general healthy population is split into heavy and light social drinkers, it is only for light social drinkers that the whole-population effect is found. This shows sub-group differences in attentional bias between heavy and light social drinkers, clarifying previous inconsistent findings (Cox, Brown, & Rowlands, 2003; Cox, Yeates, & Regan, 1999; Sharma et al., 2001). The fact that find group differences were found here without relying on individual differences (Field et al., 2011; Field et al., 2005) or alcohol priming (Cox et al., 2003; Cox et al., 1999;

Jones & Schulze, 2000; Schoenmakers et al., 2008) speaks again to the suitability of the one-shot change detection paradigm in the investigation of attentional bias and stresses the value of using psychophysical methodologies such as signal detection theory to measure subtle changes in attentional state.

The current study found that heavy social drinkers are less distracted by information relating to an additional induced attentional bias. As discussed, this may be related to the experimental sample comprising of highly educated young adults with high executive function, enhancing their ability to ignore task-irrelevant information. Increasing the demand on the PFC by requiring participants to control for multiple distractions simultaneously would be one way to test this theory. This is because there is a limit to the amount of perceptual information that can be controlled for at any one time (Lavie, 2010; Lavie, Hirst, de Fockert, & Viding, 2004), suggesting that the more irrelevant information that participants are required to ignore, the greater the demand on their cognitive control abilities and the more likely that some information will affect behaviour. Furthermore, since smoking and the taking of recreational drugs were exclusion criterion in the present study, it is possible that heavy social drinkers were only practiced at controlling for one attentional bias. It would therefore be of interest to discover if there is a limit to the extent that highly educated individuals can control for irrelevant bias-related information. If so, this would this provide further evidence that the heavy social drinkers in the current study were able to recruit existing control mechanisms to reduce the effect of behaviourally irrelevant material. Such an investigation could also provide insight into the limits of control over attentional biases. This is important, due to the large co-occurrence of addictions (and biases) primarily in young adults (Falk, Yi, & Hiller-Sturmhofel, 2006), amplified by the issue that adolescence is a time when substance experimentation is at its highest (Brown & Tapert, 2004; Kandel & Logan, 1984; Palmer et al., 2009; Tapert et al., 2003).

In conclusion, the present study examined the effect of a pre-existing attentional bias towards alcohol on the procurement of an additional induced arbitrary attentional bias. Irrelevant items relating to the arbitrary bias significantly affected light social drinkers more than heavy social drinkers, thus showing sub-group differences in a pre-clinical sample using a one-shot change detection paradigm. These findings stress the need for caution when forming conclusions relating to attentional bias using experimental paradigms that can only measure behavioural differences in reaction time, since investigations using such paradigms have produced inconsistent findings with pre-clinical testing populations. This suggests that tasks which only provide reaction time data may not be sensitive enough to detect subtle alterations in attentional settings. These findings also suggest that even in the general population, there are differences in how new attentional biases affect behaviour. It is possible that once persistent attentional control settings have been established they are difficult to interfere with. Alternatively, a decreased effect of distractions caused by an induced alteration to attentional control settings may be due to increased practice in exerting executive control over attentional biases in those who already hold one. This suggests that the distracting effects of attentional biases may differ in those who have lower executive functioning, i.e., a non-university sample, emphasising the need for appropriate control groups when studying addicted populations. Investigating the limits to which irrelevant information relating to an attentional bias can be controlled for is now of importance.

Chapter 5

Limits to Cognitive Control in Heavy Social Drinkers; Inducing Two Arbitrary Biases

Overview

It was established in Chapter 4 that light social drinkers show greater evidence of being distracted by irrelevant stimuli relating to attentional biases than heavy social drinkers, despite both groups originating from the same demographic with high executive and prefrontal cortex (PFC) functioning. Due to the established link between the PFC and higher level processing, the PFC arguably plays a role in the control of reflexive processes such as attentional bias. Individuals with lower PFC functioning are thus more susceptible to attentional bias since they do not possess the resources to control for these. It is therefore possible that attentional bias may affect behaviour differently depending on levels of PFC functioning. However, current investigations use samples where PFC function is either disrupted or cannot be appropriately compared to healthy populations. This chapter examined the effects of induced biases and limits for the control of such biases in high PFC functioning participants further by inducing two attentional biases in samples of highly-educated heavy and light social drinkers. Heavy social drinkers could only cognitively control for one induced attentional bias at a time. If two attentional biases are induced, heavy social drinkers behaved as light social drinkers suggesting a limitation of cognitive control in attentional bias in high PFC functioning adults. It was argued that the load theory of attention can account for these findings, where high cognitive load – controlling for two attentional biases – created a behavioural effect in heavy social drinkers while lower cognitive load – controlling for one attentional bias – did not.

5.1 Introduction

Executive functioning is required to establish control over irrelevant items in the environment (Banich, 2009). As discussed throughout this thesis, there is an established link between executive functioning and PFC activity (Adams et al., 1993; Crews & Boettiger, 2009; Cummings, 1993; Stuss & Alexander, 2000; Sullivan et al., 2000; Uekermann & Daum, 2008). Prefrontal activity appears to be defective in addicted populations, where substance abuse has been found to cause physical damage to the PFC (Desmond et al., 2003; George et al., 2004; Goldstein & Volkow, 2011; Goldstein et al., 2001; Medina et al., 2008; Ratti et al., 2002; Thompson et al., 2004). This feeds into the established link between implicit cognitive processing and addiction (Ryan, 2002; Wiers, Gladwin, Hofmann, Salemink, & Ridderinkhof, 2013; Wiers & Stacy, 2006). Many dual-process models of addictive behaviour (Bechara, 2005; Robinson & Berridge, 1993, 2004, 2008; Wiers & Stacy, 2006) emphasise this interplay between automatic/implicit with controlled/reflexive processes, where it is argued that substance abuse can not only affect the impulsive mechanisms, but can also affect the efficiency of the reflective processes as well (Lammers, Kuntsche, Engels, Wiers, & Kleinjan, 2013; Peeters et al., 2013; Peeters, Vollebergh, Wiers, & Field, 2014; Wiers et al., 2013). Thus, those with defective prefrontal activity arguably have lower levels of executive functioning, resulting in increased behavioural effects of implicit cognitions since these individuals do not have the resources to recruit reflective processes to control.

These links between executive functioning, PFC activity and attentional bias therefore also suggest that IQ and level of educational attainment may predict the extent to which top-down alterations to the priority map and thus, attentional bias, modulate behaviour (Coricelli & Nagel, 2009; Courtney, Ungerleider, Keil, & Haxby, 1997; Goldstein et al., 2004; Miller & Cohen, 2001; Muller & Knight, 2006; Narr et al., 2007; Shaw et al., 2006). Supporting this, those with lower executive functioning – assessed via working memory capacity – display greater predicted drug-cue associations with drug use levels than those with higher executive functioning (Grenard et al., 2008). Also, higher PFC BOLD

responses in tasks displayed on substance-related backgrounds predicted less evidence of substance-related attentional biases affecting behaviour (Hester & Garavan, 2009).

It is therefore unclear if the development of attentional biases in addicted populations is due to low levels of executive functioning independent of substance-abuse induced PFC damage, or if the PFC damage lowers executive functioning, leaving people more susceptible to attentional biases. To clarify this, the previous chapter examined attentional bias in two groups of participants with high executive functioning (university students) where it was found that those with practice at controlling for attentional biases (heavy social drinkers) were more successful at ignoring task-irrelevant distractions from newly induced attentional biases. This novel finding is arguably due to pre-existing cognitive control mechanisms in heavy social drinkers used to control for their pre-existing alcohol-related attentional bias. These settings are likely to be in constant use to avoid distracting alcohol-related stimuli to the extent that they become schematic (van Veen & Carter, 2006a, 2006b). These schemas are then applied to irrelevant distractors relating to an arbitrary induced bias. Thus, although heavy social drinkers were biased towards green stimuli, they were not distracted by it. On the other hand, light social drinkers who had no such control settings previously in place were unable to control for bias-related distractors, resulting in reduced perceptual sensitivity when presented with irrelevant bias-related distractors. However, this novel finding requires further investigation to determine if it is previous experience in controlling for attentional bias-related distractors or previous experience coupled with high executive functioning which is the driving force behind these findings.

This chapter shall therefore further examine the extent that executive functioning has on controlling for attentional biases by increasing the demand on executive functioning by inducing two arbitrary attentional biases (towards green and blue) in heavy versus light social drinkers from a university sample. Executive functioning will also be directly analysed since this was only inferred (but not tested) in previous chapters. This will be done via the reverse digit span subset of the Wechsler Adult

Intelligence Scale (Wechsler, 2008) as scores in this task are related with executive functioning processes (Benson, Hulac, & Kranzler, 2010; Hale, Hoeppner, & Fiorello, 2002). Due to participants originating from the same demographic, no differences are expected. A further aim is to investigate the potential limits of cognitive control in highly educated individuals, since controlling for multiple biases is more demanding than controlling for one bias. This is important due to the co-occurrence of substance abuse (Falk et al., 2006). This suggests that addicted populations often have biases towards multiple categories of information (e.g. to both alcohol-related and smoking-related information). It is possible that the more attentional biases an individual has to control for, the greater the behavioural effect of these biases will be due to the increased demands of the amount of information to control for (Lavie, 2010; Lavie et al., 2004). Alternatively, the physical effects of substance abuse on the PFC could have a negative effect on the control of multiple biases (Cardenas et al., 2011; Cardenas et al., 2007; Chanraud et al., 2011). The current study will overcome this by again using a pre-clinical sample of heavy social drinkers and comparing effects of multiple induced arbitrary attentional biases to light social drinkers.

It is predicted that as the cognitive load of the task increases, heavy social drinkers will become distracted by the presence of task-irrelevant bias-related information due to limitations on their pre-existing control mechanisms. This will support the initial proposal of pre-existing control mechanisms in heavy social drinkers in Chapter 4. Requiring heavy social drinkers to simultaneously control for two biases will therefore require additional cognitive resources or control mechanisms that may not be available or do not currently exist, increasing the likelihood that irrelevant bias-related information will affect behaviour. The robustness of induced attentional biases will also be examined yet further, by splitting the sample into two additional sub-groups. One group will be biased towards both arbitrary stimuli in the same experimental session; the second group will be biased towards one arbitrary stimulus in their first experimental session and biased towards the second after one week. This shall allow for an investigation of how a pre-existing bias and a secondary induced bias interrupt with attentional control settings one week after they are initially

established. If attentional control settings are persistently altered via the information sheet, evidence of both induced attentional biases in the second experimental session is expected. Furthermore, if pre-existing persistently altered attentional control settings interact with this, these finding should be different in heavy compared to light social drinkers.

5.2 Obtaining Heavy and Light Social Drinkers

Initially, an alcohol consumption questionnaire was used to generate samples of heavy and light social drinkers for the laboratory experiments (Sobell & Sobell, 1992). Alcohol-related attentional bias was then assessed via an alcohol change detection task to ascertain that heavy drinkers held an alcohol-related attentional bias. This ensured valid groups of participants completed the study.

5.2.1 Assessment of Attentional Bias to Alcohol

5.2.1.1 Method

5.2.1.1.1 Participants

Initially, 86 participants (24 males) aged 18-42 (M: 20.267, SD: 3.89) completed an alcohol consumption questionnaire (Time Line Follow Back, Sobell & Sobell, 1992) in order to obtain samples of heavy and light social drinkers. As with Chapter 4, smoking and/or the taking or recreational drugs were exclusion criteria. Participants were undergraduate students in their first year of an Applied Psychology course at Durham University. Of these, 40 participants (7 male), aged 18-21 (M: 19.05, SD: 0.96) with normal or corrected to normal vision and no colour blindness took part. There were 20 light social drinkers, and 20 heavy social drinkers. Heavy social drinkers had an average weekly consumption of 42.88 units (SD: 12.84), light social drinkers had an average weekly consumption of 10.98 units (SD: 6.41). These differed significantly: $t(38) = -9.943$, $p<.001$, $r = .849$. All participants gave their informed consent with the approval of Durham University Ethics Advisory Committee. Participants were compensated for their time in the form of course credits.

5.2.1.1.2 Apparatus, Stimuli & Procedure

Apparatus, stimuli and procedure were the same as those used in the Assessment of Attentional Bias to Alcohol method in Chapter 4 (pages 113-114).

5.2.1.2 Results

Sensitivity measured via d' was entered into a 2 (Drinker: Heavy/Light) x 4 (Trial Type: Alcohol-Alcohol/Alcohol-Neutral/Neutral-Alcohol/Neutral-Neutral) mixed factor ANOVA. Trial was a within subjects factor, Drinker was a between subjects factor. There was a main effect of Drinker: $F(1, 38) = 4.456$, $p = .042$, $r = .332$. Pairwise comparisons revealed that heavy social drinkers had significantly higher d' scores than light social drinkers (mean difference: .28). Finally, there was a significant interaction between Trial and Drinker: $F(3, 108) = 3.895$, $p = .011$. To elucidate, two repeated measures ANOVAs were conducted – one examined d' scores of Light social drinkers in all types of trial, and one examined the same for Heavy social drinkers. There was a significant main effect of trial for Light social drinkers: $F(3, 57) = 7.163$, $p < .001$. Bonferroni corrected pairwise comparisons revealed that d' scores for Neutral-Alcohol trials were significantly lower than Alcohol-Alcohol trials (mean difference: .241, $r = .680$), and Neutral-Neutral trials (mean difference: .289, $r = .802$). Likewise, there was a significant main effect of trial for Heavy social drinkers: $F(3, 57) = 6.174$, $p = .001$. Pairwise comparisons revealed that d' scores for Neutral-Alcohol trials were significantly higher than Alcohol-Alcohol trials (mean difference: .256, $r = .617$), and Alcohol-Neutral trials (mean difference: .361, $r = .648$). Furthermore independent samples t-tests examining differences between Heavy and Light social drinkers yielded only one significant result; that of Neutral-Alcohol trials: $t(38) = -4.505$, $p<.001$, $r = .590$ – see figure 5.1.

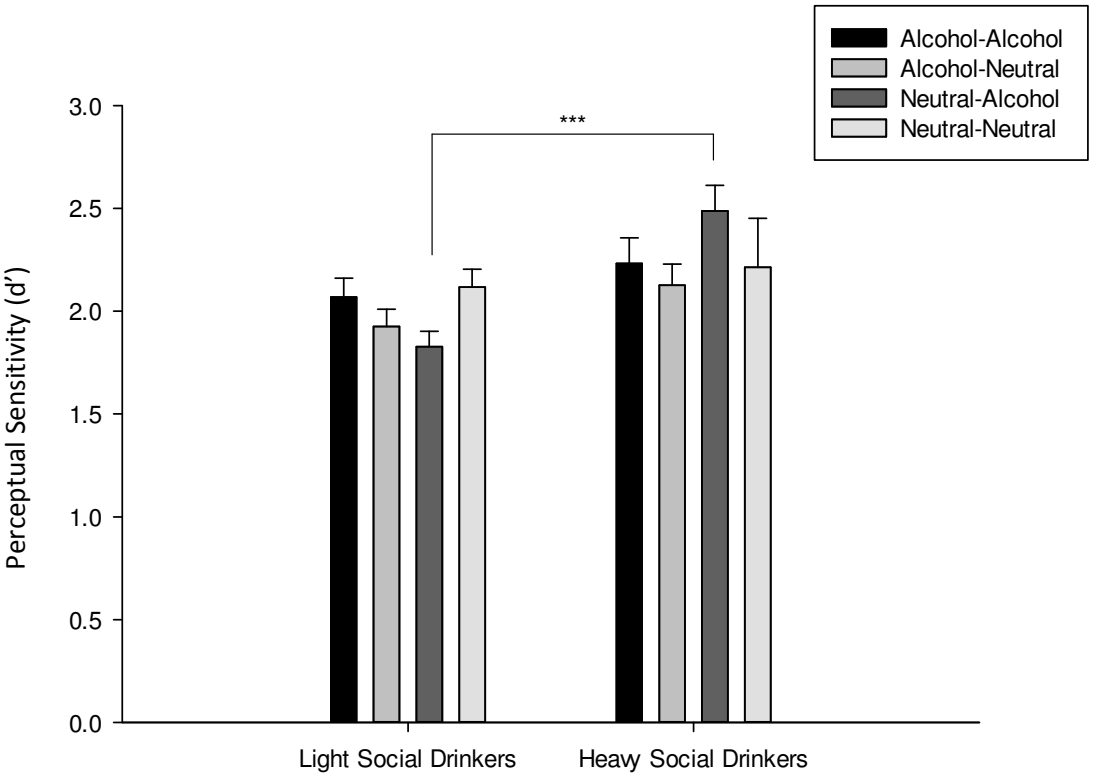

Figure 5.1: **Pre-existing alcohol-related attentional bias in light versus heavy social drinkers.** Higher d' indicates increased sensitivity to change. Sensitivity is higher in heavy social drinkers than light social drinkers when an alcohol-related image appears amongst neutral images. Error bars show standard error of the mean. *Note:* *** p<.001

5.2.2 Reverse Digit Span

5.2.2.1 Method

5.2.3.2.1 Participants

Participants were those who completed the alcohol change detection task, and completed the reverse digit span task in the same experimental session.

5.2.3.2.2 Apparatus & Stimuli

A sheet with lists of incrementally larger single digit numbers on it was used. These were generated via a random number generator. A stopwatch was also used to ensure all participants had the same amount of time to make their responses.

5.2.3.2.3 Design & Procedure

An experimenter read out lists of incrementally larger numbers beginning at three. Participants were informed that they had to repeat these back in their reverse form, and that they would have 30 seconds to recall each set. Following the successful recall of at least 75% of sets from a particular set

length, the set length would be increased by one until participants scored 33% correct or less from that set length. Reverse digit span was calculated as the total set length from the longest set where participants scored at least 75% correct.

5.2.3.3 Results

Mean digit span for Light social drinkers was 6.04 (SD: 0.99), compared to 5.83 (SD: 0.88) for Heavy social drinkers. These did not differ ($t(38) = .590$, $p = .559$). The reverse digit span between participants in the One-Week group was 5.89 (SD: 0.94), compared to 5.98 (SD: 0.94) in the Two-Week group. These also did not differ ($t(38) = -1.381$, $p = .175$). Furthermore, Reverse Digit Span did not correlate with any type of trial from any of the laboratory experiments. As such, it was concluded that all participants used in the current study did not differ in terms of their working memory or executive functioning. Consequently, reverse digit span was not entered into any analyses as a covariate.

5.3 Attentional Bias Inducement Tasks

5.3.1 Method

5.3.1.1 Participants

Participants were those who completed the alcohol change detection task.

5.3.1.2 Design

Equal numbers of heavy and light social drinkers were assigned to one of two groups. All groups received the same green information sheet at the start of the experiment and completed the change detection task. Group 1 was then immediately presented with the 2nd, blue information sheet and asked to complete a second experimental session. Following this, they were presented with the neutral, Shape information sheet and asked to complete the shape change detection task. Group 2 were invited to return in 1 week. In the 2nd session they were firstly presented with the blue information sheet then asked to complete the change detection task. This was followed by the neutral, Shape information sheet and the shape change detection task. The experiment therefore had a mixed design. There was a within subjects factor of experimental session (Session 1 v Session

2) and two between subjects' factors of Inter Session Interval (0 weeks vs 1 week) and Drinker (Light v Heavy).

5.3.1.3 Apparatus & Stimuli

Apparatus and stimuli were identical to those used in Experiments 1 and 2 (the colour change detection task and the shape change detection task) of Chapter 3. The only additional apparatus was the blue biasing information sheet which was identical to the green information sheet apart from the substitution of the word *green* for *blue*.

5.3.1.4 Procedure: Green and Blue Biasing Tasks

The procedure for the green biasing task was identical to that used in Experiment 1 of Chapter 3 (pages 79-81). In the Blue biasing experiment, the individual structure of each trial was identical to the Green biasing experiment; however the composition of trials was altered. Here, on 15% (45 trials) of trials a blue item was present and changed colour (Blue Congruent Change Trials), on 15% of trials a blue item was present in the display but a different item changed colour (Blue Incongruent Change Trials), On 15% of trials a green item was present and changed colour (Green Congruent Change Trials), on 15% of trials a green item was present in the display but a different item changed colour (Green Incongruent Change Trials), on 15% of trials both blue and green item were present but a different item changed colour (Both Incongruent Change Trial), on 15% of trials no blue or green item was present and one of the other objects changed colour (Neutral Change Trials) and on 10% of trials a blue and green item was present but no change occurred (No Change Trials). Participants completed 5 blocks of 60 trials with a 5 minute break between each block.

5.3.1.7 Procedure: Shape Task

The procedure for the shape task was identical to that used in Experiment 2 of Chapter 3 (pages 89-91). Here, on 12.5% (120 trials) of trials a green shape was present, and a different shape changed shape (Green Present Change Trials), on 12.5% of trials a green item was present but no change occurred (Green Present No-Change Trials), on 12.5% of trials a blue shape was present, and a different shape changed shape (Blue Present Change Trials), on 12.5% of trials a blue item was

present but no change occurred (Blue Present No-Change Trials), on 12.5% of trials a green and blue shape were present, and a different shape changed shape (Both Present Change Trials), on 12.5% of trials a green and blue item was present but no change occurred (Both Present No-Change Trials), on 12.5% of trials no green or blue item was present and a shape changed shape (Both Absent Change Trials) and on 12.5% of trials no green or blue item was present and no change occurred (Both Absent No Change Trials). Participants completed 12 blocks of 80 trials with a 5 minute break between each block.

5.3.2 Results

5.3.2.1 Bias Experiment: Green

Accuracy, d' and Criterion scores were entered into several 3 (Trial: Congruent Change/Incongruent Change/Neutral Change) x 2 (Inter-test Interval: Same-Week/One-Week) x 2 (Drinker: Heavy/Light) Mixed Factor ANOVAs. Trial was a within subjects factor; Inter-test Interval and Drinker were between subjects.

5.3.2.1.1 Accuracy

There was a main effect of Trial: $F(2, 72) = 77.773$, $p < .001$, $r = .721$. Accuracy for Congruent Change trials was significantly higher than for both Incongruent Change trials (mean difference: .199, $r = .892$) and Neutral Change trials (mean difference: .128, $r = .807$). Accuracy for Incongruent Change trials was significantly lower than for Neutral Change trials (mean difference: .071, $r = .593$).

5.3.2.1.2 d'

The only observed effect was a main effect of Trial: $F(2, 72) = 38.538$, $p < .001$, $r = .588$. Bonferroni corrected pairwise comparisons revealed that d' scores for Congruent Change trials were significantly higher than for both Incongruent Change trials (mean difference: 1.041, $r = .760$) and Neutral Change trials (mean difference: .808, $r = .673$). Additionally, d' scores for Incongruent Change trials was significantly lower than accuracy for Neutral Change trials (mean difference: .233, $r = .614$) – See figure 5.2.

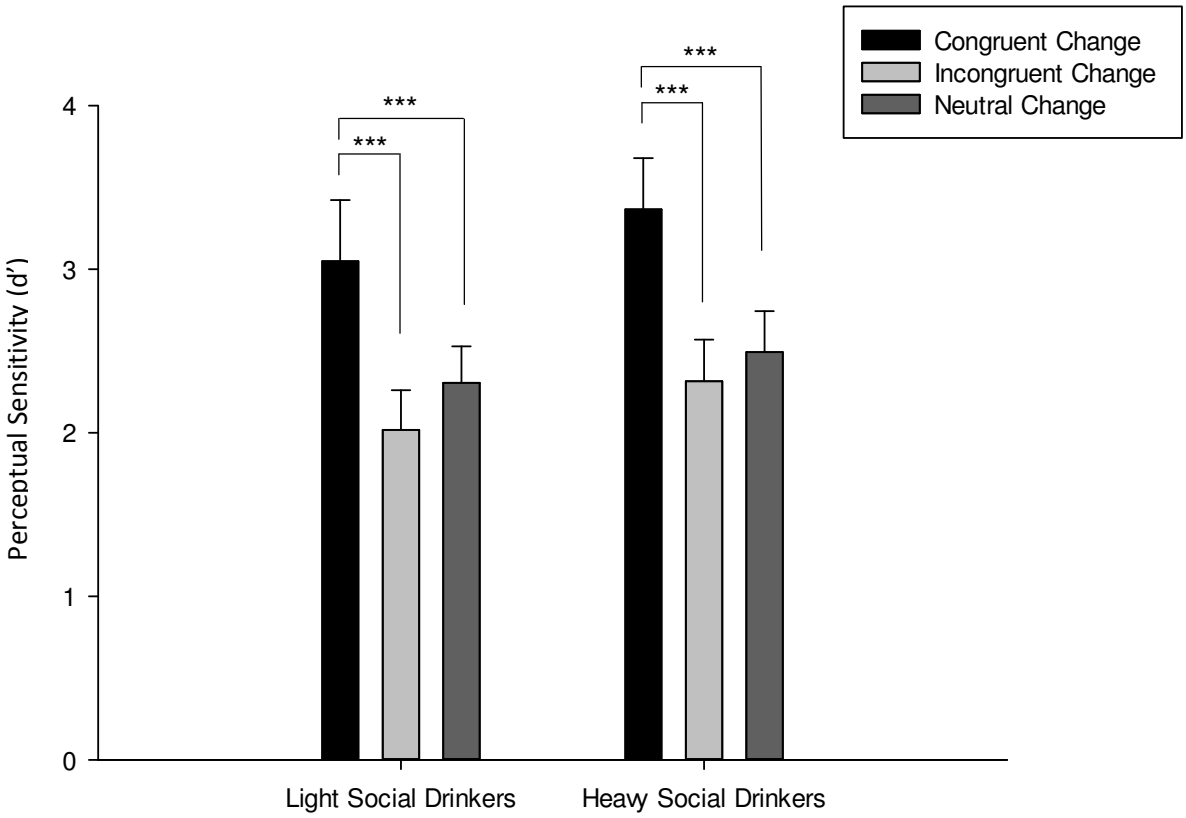

Figure 5.2: Effect of an induced attentional bias towards green in light and heavy social drinkers. Higher d' indicates increased sensitivity to change. Sensitivity is when a green item is present and changes. No differences in sensitivity are present between heavy and light social drinkers. Error bars show standard error of the mean. *Note:* *** p<.001

5.3.2.1.3 Criterion

Continuing the trend, the only observed effect was a main effect of Trial: $F(2, 72) = 37.577$, $p < .001$. Bonferroni corrected pairwise comparisons revealed that Criterion for Congruent Change trials was significantly lower than for both Incongruent Change trials (mean difference: .513, r = .757) and Neutral Change trials (mean difference: .395, r = .666). Criterion for Incongruent Change trials was significantly higher than accuracy for Neutral Change trials (mean difference: .117, r = .615).

5.3.2.2 Bias Experiment: Blue

Accuracy, d' and Criterion were entered into several 6 (Trial: Blue Congruent Change/Blue Incongruent Change/Green Congruent Change/Green Incongruent Change/Both Incongruent Change /Neutral Change) x 2 (Inter-test Interval: Same-Week/One-Week) x 2 (Drinker: Heavy/Light) Mixed Factor ANOVAs. Trial was within-subjects; Inter-test Interval and Drinker were between-subjects.

5.3.2.2.1 Accuracy

There was a significant main effect of Drinker: F(1, 36) = 4.584, p = .039, r = .3361. Heavy social drinkers were more accurate (M: .807) than light social drinkers (M: .739) by an average of .068. There was also a main effect of Trial: F(1, 180) = 90.263, p <.001, r = .578. Pairwise comparisons revealed several significant differences. These are displayed in Table 5.1.

Table 5.1
Significant differences in mean accuracy between different types of trial, following an induced attentional bias towards both green and blue.

Trial	Comparison Trial	Mean Difference	P	Effect Size (r)
Green Congruent	Green Incongruent	.138	<.001	.779
Green Congruent	Blue Congruent	.124	<.001	.820
Green Congruent	Both Incongruent	.296	<.001	.944
Blue Congruent	Green Incongruent	.144	<.001	.761
Blue Congruent	Blue Congruent	.130	<.001	.747
Blue Congruent	Both Incongruent	.302	<.001	.932
Green Incongruent	Both Incongruent	.159	<.001	.806
Green Incongruent	Neutral Change	-.164	<.001	.763
Blue Incongruent	Both Incongruent	.172	<.001	.886
Blue Incongruent	Neutral Change	-.150	<.001	.777
Both Incongruent	Neutral Change	-.322	<.001	.919

Finally, the ANOVA showed a significant interaction between Trial and Drinker: F(5, 180) = 2.641, p = .025, r = .120. To elucidate, two repeated measures ANOVAs were conducted. One compared the accuracy of each Trial Type for Light social drinkers, and one for Heavy social drinkers. The ANOVA for Light social drinkers was significant: F(5, 95) = 29.476, p<.001, r = .487. Bonferroni corrected pairwise comparisons revealed many significant comparisons. These are all displayed in table 5.2.

Table 5.2
Significant differences in mean accuracy between different types of trial, following an induced attentional bias towards both green and blue in light social drinkers

Trial	Comparison Trial	Mean Difference	P	r
Green Congruent	Green Incongruent	.153	.001	.775
Green Congruent	Blue Congruent	.125	<.001	.790
Green Congruent	Both Incongruent	.249	<.001	.927
Blue Congruent	Green Incongruent	.165	.002	.746
Blue Congruent	Blue Congruent	.137	.013	.672
Blue Congruent	Both Incongruent	.261	<.001	.870
Green Incongruent	Neutral Change	-.193	.001	.752
Blue Incongruent	Both Incongruent	.124	<.001	.816
Blue Incongruent	Neutral Change	-.165	.002	.746
Both Incongruent	Neutral Change	-.289	<.001	.898

The ANOVA for Heavy social drinkers was also significant: $F(5, 95) = 76.657$, $p<.001$, $r = .668$. Again, Bonferroni corrected pairwise comparisons revealed many significant differences. These are all displayed in Table 5.3, while the full Drinker x Trial interaction is displayed in Figure 5.3.

Table 5.3
Significant differences in mean accuracy between different types of trial, following an induced attentional bias towards both green and blue in heavy social drinkers

Trial	Comparison Trial	Mean Difference	P	Effect Size (r)
Green Congruent	Green Incongruent	.122	.001	.768
Green Congruent	Blue Congruent	.123	<.001	.837
Green Congruent	Both Incongruent	.343	<.001	.953
Blue Congruent	Green Incongruent	.123	<.001	.780
Blue Congruent	Blue Incongruent	.124	<.001	.852
Blue Congruent	Both Incongruent	.344	<.001	.968
Green Incongruent	Both Incongruent	.221	<.001	.798
Green Incongruent	Neutral Change	-.134	.001	.894
Blue Incongruent	Both Incongruent	.220	<.001	.914
Blue Incongruent	Neutral Change	.135	<.001	.790
Both Incongruent	Neutral Change	-.355	<.001	.929

Both Heavy and Light social drinkers are significantly more accurate in Green Congruent Change and Blue Congruent Change trials than Green Incongruent, Blue Incongruent, and Both Incongruent trials – thus both Heavy and Light drinkers show evidence of an induced attentional bias towards both green and blue stimuli. However, only for Heavy social drinkers is there a significant difference between Green Incongruent and Both Incongruent trials. Thus, when an attentional bias towards both green and blue items is induced and stimuli of both colours are present, it appears to have a disproportionate effect in Heavy social drinkers than Light social drinkers; light social drinkers are as accurate with one distraction present as they are with two, whereas Heavy social drinkers are not as effected with one distraction present than they are with two. Furthermore, the effect sizes seem to suggest that the differences that occur are also more extreme in places for Heavy social drinkers.

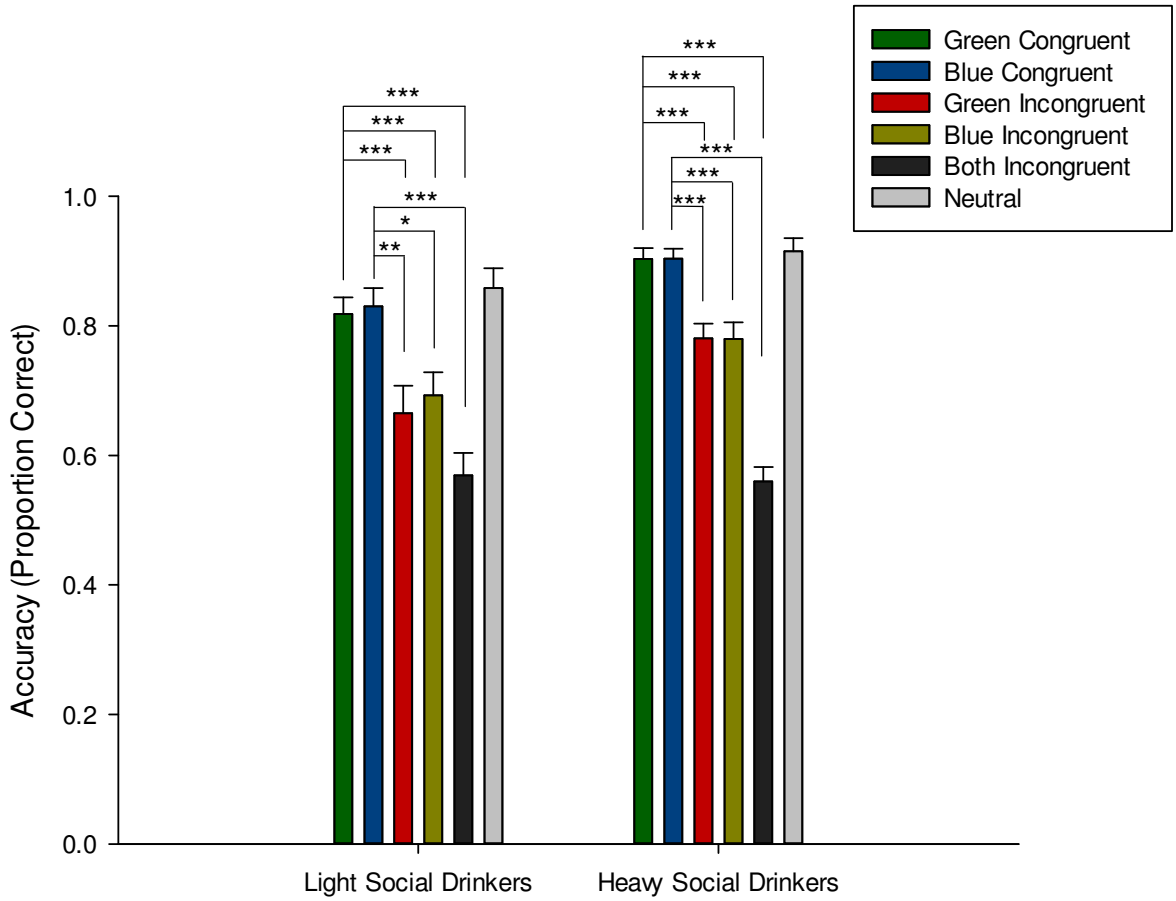

Figure 5.3: Differences in mean accuracy for all types of trial in heavy versus light social drinkers.
Note: * P<.05, ** P<.005, *** p<.001

To examine these differences further, a series of independent samples t-tests were conducted, comparing accuracy in all types of trial between Heavy and Light social drinkers. The results of these are displayed in table 5.4, below.

Table 5.4
Significant differences in mean accuracy for different types of trial, following an induced attentional bias towards both green and blue between heavy and light social drinkers

Trial	M: Light SD	M: Heavy SD	Mean Diff	t	p	r
Green Congruent	.8181	.9030	.0848	2.745	.009	.4068
Blue Congruent	.8299	.9035	.0736	2.278	.030	.3466
Green Incongruent	.6652	.7805	.1153	2.383	.022	.3606
Blue Incongruent	.6929	.7795	.0866	1.969	.056	.3043
Both Incongruent	.5689	.5597	.0091	.222	.826	.0359
Neutral Change	.8584	.9149	.0565	1.534	.133	.2415

Heavy social drinkers are significantly better at detecting all types of change compared to light social drinkers, apart from when no biased stimulus is present, and when a blue and green stimulus are present. In latter trials, Heavy social drinkers appear to be just as distracted by two induced arbitrary biases as Light social drinkers are, suggesting limitations on the extent to which attentional biases can be controlled.

5.3.2.2.2 d'

For the d' analysis, the only observed effect was a main effect of Trial: $F(5, 180) = 35.838$, $p < .001$, $r = .407$. Bonferroni corrected pairwise comparisons revealed many significant differences which are all displayed in Table 5.5 along with the mean differences and the effect sizes, calculated via r-values.

Table 5.5
Significant differences in mean d' scores between different types of trial, following an induced attentional bias towards both areen and blue

Trial	Comparison Trial	Mean Difference	P	Effect Size (r)
Green Congruent	Green Incongruent	.631	<.001	.714
Green Congruent	Blue Incongruent	.594	<.001	.732
Green Congruent	Both Incongruent	1.122	<.001	.880
Green Congruent	Neutral Change	-.871	.022	.497
Blue Congruent	Green Incongruent	.734	<.001	.708
Blue Congruent	Blue Congruent	.697	<.001	.716
Blue Congruent	Both Incongruent	1.225	<.001	.844
Green Incongruent	Both Incongruent	.491	<.001	.802
Green Incongruent	Neutral Change	-1.502	<.001	.708
Blue Incongruent	Both Incongruent	.528	<.001	.866
Blue Incongruent	Neutral Change	-1.465	<.001	.699
Both Incongruent	Neutral Change	-1.993	<.001	.787

There was no difference in d' scores between Green Congruent and Blue Congruent trials, thus participants' sensitivity to change did not differ towards green and blue stimuli. Both Green Congruent and Blue Congruent trials had significantly higher d' scores than Green Incongruent and Blue Incongruent trials. Both Incongruent trials had significantly lower d' scores than for any other type of trial. Therefore it spears as if the two induced attentional biases had an additive effect, meaning that when they were both present and did not change, sensitivity to detect change was at its lowest.

5.3.2.2.3 Criterion

The ANOVA revealed two significant effects. The first was a main effect of Drinker: $F(1, 36) = 5.137$, $p = .030$, $r = .3534$. Bonferroni adjusted pairwise comparisons showed that Heavy social drinkers had significantly lower Criterion scores (M: .088) than Light social drinkers (M: .371). Since lower Criterion is indicative of more liberal responses, this suggests that Heavy social drinkers were, on the whole, more liberal than Light social drinkers. The second main effect was for Trial: $F(5, 180) = 35.351$, $p < .001$, $r = .554$. Bonferroni corrected pairwise comparisons revealed many significant comparisons. These are all displayed in Table 5.6, below.

Table 5.6
Significant differences in mean Criterion scores between different types of trial, following an induced attentional bias towards both green and blue

Trial	Comparison Trial	Mean Difference	P	r
Green Congruent	Green Incongruent	-.273	<.001	.664
Green Congruent	Blue Congruent	-.265	<.001	.691
Green Congruent	Both Incongruent	-.526	<.001	.864
Green Congruent	Neutral Change	.474	.008	.436
Blue Congruent	Green Incongruent	-.329	<.001	.688
Blue Congruent	Blue Congruent	-.320	<.001	.696
Blue Congruent	Both Incongruent	-.581	<.001	.841
Blue Congruent	Neutral Change	.419	.026	.492
Green Incongruent	Both Incongruent	-.253	<.001	.795
Green Incongruent	Neutral Change	.747	<.001	.702
Blue Incongruent	Both Incongruent	-.261	<.001	.877
Blue Incongruent	Neutral Change	.738	<.001	.699
Both Incongruent	Neutral Change	1	<.001	.786

Crucially, when no green or blue stimulus was present, Criterion scores were significantly lower. Moreover, when both a green and blue stimuli were present, Criterion scores were significantly higher than for any other type of trial, suggesting an additive effect. Finally, there was no difference in between Blue change and Green change trials. Thus, an additional bias towards Blue did not negate the existing bias towards green.

5.3.2.3 Shape Experiment

Accuracy was entered into a 4 (Bias: Green Present/Blue Present/Both Present/Both Absent) x 2 (Trial: Change/No Change) x 2 (Inter-test Interval: Same-Week/One-Week) x 2 (Drinker: Heavy/Light) Mixed Factor ANOVA. Bias and Trial were within-subjects; Inter-test Interval and Drinker were between-subjects. d' and Criterion were entered into two 4 (Bias: Green Present/Blue Present/Both

Present/Both Absent) x 2 (Inter-test Interval: Same-Week/One-Week) x 2 (Drinker: Heavy/Light) Mixed Factor ANOVAs. Bias was within-subjects; Inter-test Interval and Drinker were between-subjects.

5.3.2.3.1 Accuracy

The ANOVA revealed a main effect of Trial: $F(1,36) = 72.924$, $p<.001$. Unsurprisingly, No Change trials were detected significantly more accurately (M: .911) than Change trials (M: .705, $r = .818$). There was also a main effect of Bias: $F(3, 108) = 11.119$, $p<.001$, $r = .306$. Pairwise comparisons following a Bonferroni correction revealed several significant differences. Firstly, Green Present trials were detected significantly more accurately than Both Present trials (mean difference: .024, $p <.049$, $r = .423$). On the other hand, Green Present trials were detected significantly less accurately than Both Absent trials (mean difference = .023, $p = .036$, $r = .437$). Blue Present trials were detected significantly more accurately than Both Present trials (mean difference: .039, $p = .001$, $r = .570$). Finally, Both Absent trials were detected significantly more accurately than Both Present trials (mean difference: .048, $p = .001$, $r = .590$).

There was also a significant interaction between Bias and Trial: $F(3, 108) = 20.271$, $p<.001$, $r = .394$. To investigate, two repeated measures ANOVAs were conducted, one examining accuracy in Change trials for all types of bias and one doing the same for No Change trials. The ANOVA for Change trials was significant: $F(3,117) = 21.304$, $p<.001$, $r = .392$. Bonferroni corrected pairwise comparisons revealed that accuracy in all types of Bias were significantly different from each other apart from Green Present and Blue Present trials. Comparing Green Present trials to Both Present trials, the mean difference was .072 ($p = .001$, $r = .572$), and compared to Both Absent trials, the mean difference was .05 ($p = .012$, $r = .468$). Comparing Blue Present trials to Both Present trials, the mean difference was .073 ($p = .001$, $r = .566$), and compared to Both Absent trials, the mean difference was .048 ($p = .014$, $r = .463$). Finally, comparing Both Present trials to Both absent trials, the mean difference was .122 ($p<.001$, $r = .706$). The ANOVA for No Change trials was also significant: $F(3,117) = 2.951$, $p = .036$, $r = .157$. The only significant difference found was between Both Present trials (M:

.922) compared to Both Absent trials (M: .895, p = .02, r = .362). This suggests that participants were just as distracted when one biased shape was present, but the addition of a second biased shape in the same array caused participants to miss more changes and report more correct rejections.

Finally, the ANOVA revealed a significant three-way interaction between Bias, Trial and Drinker: $F(3,108) = 15.599$, $p<.001$, $r = .355$. This was examined in further detail by looking at the interaction between Bias and Trial separately for light social drinkers compared to heavy social drinkers. The ANOVA for light social drinkers revealed a significant main effect of Trial: $F(1,19) = 40.377$, $p<.001$ $r = .825$. As expected, No Change trials were detected significantly more accurately (M: .915) than Change trials (M: .915). There was also a main effect of Bias: $F(3,57) = 3.274$, $p = .047$, $r = .233$. Pairwise comparisons revealed that Both Absent trials were detected significantly more accurately (M: .811) than Both Present trials (M: .772, p = .04, r = .451). Finally, for light social drinkers there was a significant Bias x Trial interaction: $F(3,57) = 3.944$, $p = .025$, $r = .254$. This was further investigated via two Repeated Measures ANOVAS – one examining accuracy across all types of bias for Change trials, and another doing the same for No Change trials. The ANOVA for Change trials was significant: $F(3,57) = 4.801$, $p = .031$, $r = .279$. Pairwise comparisons revealed that accuracy for Both Absent trials was significantly higher than for all other types of bias. Comparing to Green Present trials, the mean difference was .051 (p = .05, r = .427). Comparing against Blue Present trials, the mean difference was .056 (p = .035, r = .461). Finally, comparing against Both Present trials, the mean difference was .061 (p = .021, r = .499). The ANOVA for No Change Trials was non-significant: $F(3,57) = 2.336$, $p = .118$, $r = .198$.

The ANOVA for heavy social drinkers revealed a significant main effect of Trial: $F(1,19) = 36.867$, $p<.001$, $r = .812$. As expected, No Change trials were detected significantly more accurately (M: .906) than Change trials (M: .740). There was also a main effect of Bias: $F(3,57) = 9.085$, $p<.001$, $r = .370$. Both Present trials were detected significantly less accurately (M: .788) than Green Present trials (M: .820, p = .022, r = .514), Blue Present trials (M: .841, p = .001, r = .673) and Both Absent trials (M:

.844, p<.001, r = .717). Finally, for heavy social drinkers there was a significant Bias x Trial interaction: F(3,57) = 28.242, p<.001, r = .576. This was further investigated via two Repeated Measures ANOVAS – one examining accuracy across all types of bias for Change trials, and another doing the same for No Change trials. The ANOVA for Change trials was significant: F(3,57) = 30.070, p<.001, r = .588. Accuracy in Both Present trials was significantly lower than for all other types of bias. Comparing to Green Present trials, the mean difference was .134 (p<.001, r = .766). Comparing against Blue Present trials, the mean difference was .142 (p<.001, r = .794). Finally, comparing against Both Absent trials, the mean difference was .182 (p<.001, r = .864). The ANOVA for No Change Trials was also significant: F(3,57) = 7.434, p = .001, r = .340. Accuracy for Both Present trials was significantly higher than for all other types of bias. Comparing to Green Present trials, the mean difference was .071 (p<.001, r = .706). Comparing against Blue Present trials, the mean difference was .036 (p = .023, r = .493). Finally, comparing against Both Absent trials, the mean difference was .071 (p<.001, r = .723). This suggests that heavy social drinkers were distracted when both a green and blue shape was present, since these trials resulted in significantly more misses and correct rejections. Figure 5.4 shows the differences in accuracy in all Change trials for Light and Heavy social drinkers.

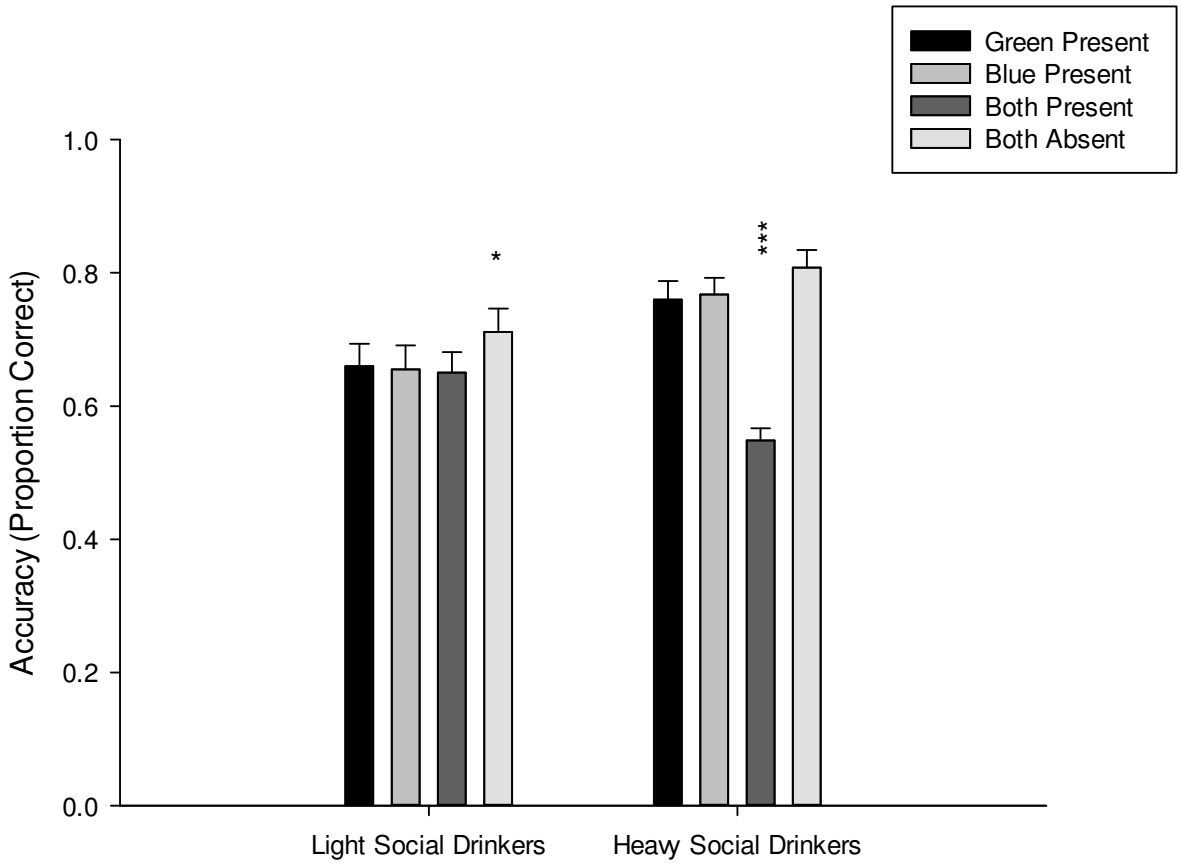

Figure 5.4: **Differences in accuracy for all types of Change trial in Heavy and Light social drinkers**. Light social drinkers were significantly more accurate in Neither Present trials, whereas Heavy social drinkers were significantly more inaccurate in Both Present trials. *Note:* * p<.05, *** p<.001

5.3.2.3.2 d' and Criterion

The ANOVA for calculated d' scores revealed no significant effects, suggesting that unlike when one attentional bias is induced, when two attentional biases are induced there is no effect on perceptual sensitivity. This shall be addressed in the Discussion. However, the ANOVA for calculated Criterion scores revealed several effects. Firstly, there was a main effect of Bias: $F(3,108) = 10.863$, $p<.001$, $r = .302$. Bonferroni corrected pairwise comparisons revealed that Criterion scores for Both Present trials was significantly higher than for all other types of bias. Comparing against Green Present trials, the mean difference was .251 ($p = .001$, $r = .504$). Comparing against Blue Present trials, the mean difference was .161 ($p = .012$, $r = .404$). Finally, comparing against Both Absent trials, the mean difference was .352 ($p<.001$, $r = .649$). Additionally, Both Absent trials also had significantly lower Criterion scores than Blue Present trials (mean difference: .191, $p = .006$, $r = .435$).

There was also an interaction between Bias and Drinker: F(3,108) = 12.592, p<.001, r = .323 – see Figure 5.5. This was investigated via two repeated measures ANOVAs, one investigating Criterion scores of all types of bias for light social drinkers, and another doing the same for heavy social drinkers.

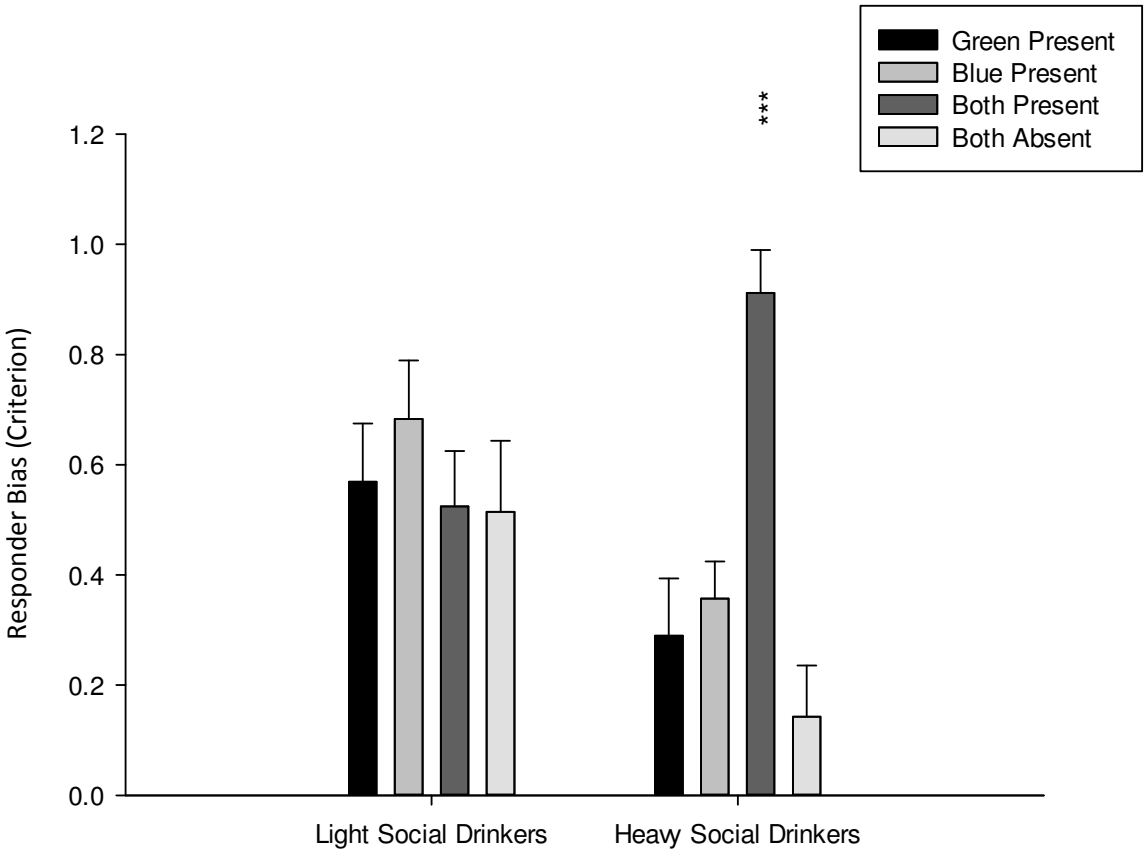

Figure 5.5: **Significant interaction in C-Scores between Trial and Drinker**. Higher C-Score is indicative of more Conservative Responses. No difference between different Trial types was observed for light social drinkers. Heavy social drinkers had significantly high C-Scores in Both Present trials. *Note:* * p<.05, *** p<.001

The ANOVA for light social drinkers was non-significant: F(3,57) = 1.783, p = .161, r = .174. Thus, Criterion scores did not differ between the types of bias in light social drinkers. The ANOVA for heavy social drinkers, however, was significant: F(3,57) = 18.549, p<.001, r = .496. Criterion scores for Both Present trials were significantly higher than for all other types of trial. Comparing against Green Present trials, the mean difference was .548 (p<.001, r = .685). Comparing against Blue Present trials the mean difference was .480 (p<.001, r = .732). Finally, comparing against Both Absent trials, the mean difference was .694 (p<.001, r = .861). Since a higher Criterion is indicative of more conservative responses, this suggests that heavy social drinkers became more conservative with

their responses only when both a green and blue shape were present in the array, thus only with multiple bias-related stimuli present did it cause a change in behaviour in heavy social drinkers.

Finally, it was speculated that the size of the difference in Criterion scores of Both Present compared to all other trials may have been masking other differences present. This was further investigated by re-running the ANOVA examining Criterion scores for heavy social drinkers with the removal of Both Present trials. Thus, a 3-Way Repeated Factor ANOVA was conducted examining Criterion scores in heavy social drinkers. The only within subjects factor was Trial (Green Present/Blue Present/Both Absent). The ANOVA was significant: $F(2,38) = 3.393$, $p = .044$, $r = .286$. Criterion for Green Present trials did not differ from Blue Present trials ($p = .420$, $r = .186$). Similarly, Criterion for Green Present trials did not differ from Both Absent ($p = .102$, $r = .375$). However, Criterion for Blue Present trials did differ from Both Absent ($p = .021$, $r = .501$). Thus, heavy social drinkers were significantly more conservative wither their responses in Blue Present trials. This is likely due to this being sequentially the second bias they were required to control for, causing a shift in behaviour.

5.4 Discussion

This study developed the findings of Chapter 4 where it was shown that light social drinkers were more distracted by irrelevant bias-related items than heavy social drinkers. It was argued that this was due to pre-existing cognitive control mechanisms held by heavy social drinkers in order to control for a pre-existing attentional bias towards alcohol. The current study supports this; however it places a limitation on this cognitive control. Here, heavy social drinkers were only able to control for one induced attentional bias. When two biases were induced, and stimuli relating to both biases were present (but irrelevant), heavy social drinkers altered how they performed in the task, becoming more conservative with their responses resulting in reduced accuracy in trials when objects relating to two induced biases were present but irrelevant. It is possible that this is due to an increase in the cognitive demands of the task. With no pre-existing control mechanisms in place, controlling for an attentional bias is cognitively demanding. Hence, light social drinkers are more affected by one bias-related stimulus than heavy social drinkers. However, with two induced biases,

the cognitive demands of the task increase and appear to go beyond the pre-existing control mechanisms of heavy social drinkers. Subsequently, when both are present they cause heavy social drinkers to alter their behaviour.

This explanation corresponds with the load theory of attention (Carmel, Thorne, Rees, & Lavie, 2011; Forster & Lavie, 2009, 2011; Lavie, 1995, 2005). Load theory stresses the importance of perceptual load in visual tasks and the distinction between perceptual load and cognitive control. Tasks high in perceptual load that engage full perceptual processing leave no capacity for the processing of irrelevant distractors. In such cases, irrelevant distractors fail to initially capture attention as early selection is inhibited. This proposal has received a vast amount of empirical support (Forster & Lavie, 2007; Lavie, 2005, 2006; Lavie & de Fockert, 2003, 2005, 2006), which has also been extended to include 'real life' distractions in daily living (Forster & Lavie, 2007; Wallace & Vodanovich, 2003). Importantly, load theory is also supported by neurobiological data showing that the neural processing of irrelevant stimuli known to be associated with particular brain regions (e.g. moving objects for area V5) is significantly reduced in conditions of high perceptual load (Muggleton, Lamb, Walsh, & Lavie, 2008; Rees, Frith, & Lavie, 1997). This not only exists for lower-level processing of stimuli, but also for higher, more complex processing in sub-clinical populations of anxious individuals (Bishop, Jenkins, & Lawrence, 2007; Pessoa, Padmala, & Morland, 2005). In Lavie's original studies, low load conditions had a single item and a flanker giving two items in the display. It could therefore be argued in the current experiments that having six (colour change detection task) or four (shape change detection task) items present results in tasks that are high in perceptual load. However, given that green items are distractors, they should be ignored (especially so for the shape task). This leaves only three behaviourally relevant items and thus a task that is arguably low in perceptual load. Moreover, the tasks require no manipulation of stimuli – just a comparison of two arrays. Finally, the fact that detection of changes in the control experiment (Chapter 3) was not at chance strongly suggests that all items are perceived, which is thus indicative of low perceptual load. Consequently in the present experiments, the bias-related stimuli should go on to capture attention.

When an item is attended to, load theory goes on to argue that cognitive control mechanisms are then required to mediate the effect of the attended stimulus on behaviour (Lavie, 1995, 2010; Lavie et al., 2004). Cognitive control mechanisms are higher-level processes that are also referred to as executive functioning (Lavie, 2010). If these processes are not already in use, cognitive load is said to be low and thus executive functioning and cognitive control mechanisms can be employed (Lavie, 2010; Lavie et al., 2004). Likewise, if these resources are currently in use they cannot be utilised and cognitive load is said to be high (de Fockert, Rees, Frith, & Lavie, 2001; Lavie et al., 2004; Nikolaou et al., 2013). Tasks high in cognitive load therefore leave fewer resources to control for the processing of irrelevant distractors and as a result, irrelevant distractors are processed and will have a behavioural effect (Lavie et al., 2004). In terms of attentional biases, this suggests that when a bias-related item has been attended to, the resources available to cognitively control for the stimulus will determine the effect that the stimulus has on behaviour. This explains why in the current experiment, it is only when both biased stimuli were present but irrelevant did they have an effect on heavy social drinkers since trying to control for/suppress two irrelevant items is more cognitively demanding than trying to suppress one. As heavy social drinkers with high executive functioning are more practiced and more able to control for irrelevant bias-related objects, this implies that it takes an increased amount of cognitive load to produce the decrement in performance as that observed in light social drinkers (this decrement in accuracy in heavy social drinkers caused by more conservative responding, not a decrease in perceptual sensitivity). Thus, the cognitive load caused by the presence of two irrelevant bias-related stimuli results in no difference in accuracy between people with pre-existing control mechanisms (heavy social drinkers) and people with no pre-existing control mechanisms (light social drinkers).

The current study also rectifies a potential issue with the previous chapter. In Chapter 4, heavy and light social drinkers were all from the same demographic of high-attaining individuals at a top UK university (Education, 2012). Thus it was argued that these participants had comparable executive and PFC functioning (Conway, Cowan, & Bunting, 2001; Conway et al., 2005; Kane & Engle, 2002;

Miller, 2000). However, there was no measure taken of executive functioning thus no empirical evidence to back this up. The current study remedies this by analysing reverse digit span – known to be related to higher-level functioning and executive control (Dahlin, Neely, Larsson, Backman, & Nyberg, 2008; Dahlin, Nyberg, Backman, & Neely, 2008; Insel, Morrow, Brewer, & Figueredo, 2006). These findings suggest that the sample used in Chapter 4 had comparable levels of executive function meaning that performance in the attentional bias tasks were therefore due to levels of social drinking and pre-existing attentional bias.

Curiously, when biased stimuli were present but irrelevant in the current study, despite differences in accuracy there were no differences in perceptual sensitivity between heavy and light social drinkers. However, response bias (Criterion scores) did change. In signal detection theory, Criterion can change irrespective of sensitivity (Macmillan & Creelman, 2005). Differences in perceptual sensitivity refers to the ability to discriminate between options (distinguish between change and no change trials), whereas response bias is the strategy used to determine responses. When bias-related items were present but irrelevant, participants' ability to discriminate between change and no change trials did not differ, however the strategy they used to make their responses did.

This further supports the explanation of load theory, since this states that with reduced cognitive control, irrelevant distractors are more likely to go on to influence behaviour (Conway et al., 2001; Kane & Engle, 2002). Here, this was in reduced accuracy towards detecting changes in trials when items relating to two attentional biases were present. These changes in accuracy don't stem from changes in perceptual sensitivity, but from a movement of the response criterion in heavy social drinkers, causing them to be more conservative with their responses (detecting fewer changes but fewer false positives). This is in conflict with studies suggesting that heavy social drinkers are more reckless (Perry & Carrol, 2008), as the current study found a change towards more conservative not more liberal responses. Reasons for this are unknown and require investigation, but it may be related to their pre-existing heavy drinking, resulting alcohol-related attentional bias and having to

control alcohol-seeking behaviour triggered by alcohol-related cues while trying to continue with demanding studies. However, this is only speculative and further work could examine this further.

Load theory argues that high perceptual load results in inattentional blindness (Mack, 2003; Mack & Rock, 1998) and reduced effects of distractors whereas high cognitive load results in irrelevant stimuli being perceived and processed. However, a recent theory by Van Dillen, Papies and Hoffmann (2013) proposes that high cognitive load can actually facilitate self-regulation. They offer results from four behavioural experiments that suggest that in tasks of high cognitive load (rehearsing an 8-digit number), participants could clearly see high-valence stimuli (images of tasty food), but they did not have the cognitive capabilities left to process the tempting qualities of these. This would mean that in the current experiments when cognitive load was high, irrelevant bias-related distractions would have been processed less thoroughly and so would have had a reduced impact on behaviour than in low-load settings (Van Dillen, Papies, & Hofmann, 2013). While it could be argued that becoming more conservative in responding may reflect facilitation in self-regulation, the primary argument of Van Dillen et al. (2013) is that the facilitation of self-regulation stems from the biased qualities of the stimuli are not being processed. The current study does not support this argument since it was only when the cognitive demands of the task were at their highest (when both green and blue shapes were present) that behaviour was affected in heavy social drinkers. This suggests that the biased qualities of the irrelevant stimuli (the colours of the shapes) were still being fully processed in the high load task as they affected behaviour.

The current findings that participants with high executive functioning exhibit attentional biases in unique ways relating to cognitive control is supported by studies investigating the effects of differing doses of alcohol on attentional bias (Duka & Townshend, 2004; Field et al., 2005; Montgomery et al., 2010; Rose & Duka, 2007; Schoenmakers et al., 2008). In Montgomery et al. (2010) social users of cocaine were found to only show an attentional bias towards cocaine related items after a moderate dose of alcohol. This was explained this via the incentive-sensitisation theory of drug use (Franken,

2003; Robinson & Berridge, 1993, 2000, 2008): drug-related stimuli elicit reward-related dopamine responses, causing drug-related stimuli to attract attention (Franken, 2003; Franken et al., 2005; Franken et al., 2004). Since alcohol is also known to trigger a dopamine response (Boileau et al., 2003), administering alcohol should raise the attentional bias of a variety of substances by raising their incentive-motivational properties. However, while exact ratios were not given, Montgomery et al. (2010) state that participants were recruited from a university sample. It is possible that the alcohol dose did not raise the attentional bias of cocaine-related stimuli, but instead decreased PFC functioning which decreased the amount of cognitive control participants had in the task, reducing the control they had over cocaine-related stimuli on behaviour. The placebo group did not show this effect since their PFCs were not disrupted thus had greater cognitive control over the task.

A recent study by Nickolaou et al. (2013) initially appears to support Montgomery et al.'s (2010) findings, as they found an increase in amygdala activity and little change in PFC activity following low doses of alcohol on an alcohol attentional bias task. Their result may not simply be a raise in amygdala activity, but could reflect less control of the PFC of the biased stimuli resulting in the increase in amygdala activity. This is supported by a recent study employing the use of transcranial direct current stimulation (tDCS) over left dorsolateral PFC in depressed patients (Wolkenstein & Plewnia, 2013). tDCS is a neurostimulatory technique, whereby an electrical current is passed between two electrodes that are affixed to the scalp – one anodal, and one cathodal. These electrodes manipulate the excitability of the underlying cortex by increasing (through cathodal stimulation) or decreasing (through anodal stimulation) the threshold by which the underlying neurons fire (Ball, Lane, Smith, & Ellison, 2013; Hsu et al., 2011; Javadi & Walsh, 2012; Nitsche & Paulus, 2000). Here, Anodal tDCS was found to improve cognitive control over negative emotional images and abolish the emotional attentional bias held by depressed patients. This suggests that increasing PFC activity increases executive functioning, allowing for greater control over incoming sensory information.

Further evidence that increasing PFC function may aid cognitive control stems from studies exploring the link between trait mindfulness and mindfulness training on the amelioration of attentional bias. High trait mindfulness and mindfulness training are associated with larger reductions in alcohol-related attentional bias (Garland, 2011; Garland, Boettiger, Gaylord, Chanon, & Howard, 2012; Garland, Gaylord, Boettiger, & Howard, 2010). Moreover, early findings suggest that mindfulness-oriented recovery is an effective treatment option for opioid-dependent patients (Garland et al., 2014). This, combined with findings that trait mindfulness and mindfulness training are associated with increased PFC activation (Brown, Goodman, & Inzlicht, 2013; Creswell, Way, Eisenberger, & Lieberman, 2007; Dickenson, Berkman, Arch, & Lieberman, 2013; Modinos, Ormel, & Aleman, 2010) strongly suggests a link between heightened PFC activity and cognitive control over attentional biases. However, while these findings do suggest a causative link between high PFC and heightened cognitive control over attentional biases, the use of depressed patients (Wolkenstein & Plewnia, 2013) introduces potential confounds resulting from the emotional connotations and additional neural processing occurring alongside the attentional bias (Janes et al., 2010). One way to provide more conclusive data would be to artificially change the cortical excitability of the PFC via tDCS following the inducement of an arbitrary attentional bias, and then examine the extent to which irrelevant, bias-related items interfere with behaviour (see Chapter 6).

In summary, the current study expanded previous findings that highly educated light social drinkers compared to heavy social drinkers exhibit greater amounts of distractibility when presented with irrelevant, arbitrary bias-related stimuli. This was achieved by induced two non-emotional attentional biases in highly educated heavy and light social drinkers with highly exercised PFCs, and thus high levels of executive functioning. Heavy social drinkers were significantly less affected by a single induced bias than light drinkers. However when items relating to both biases were present but irrelevant, heavy social drinkers' became more conservative in their responses, which caused an alteration in their accuracy meaning that heavy drinkers' accuracy matched that of light drinkers. This is arguably due to heavy social drinkers using practiced cognitive control mechanisms when

confronted with one biased stimulus, but when presented with two biased stimuli the marked increase in cognitive load resulted in the biased stimuli affecting behaviour. Examining the role of the PFC in the cognitive control of attentional bias further could expand these findings to ascertain if using a sample of highly educated individuals with high executive functioning does play a significant role in the extent to which attentional biases can be controlled.

Chapter 6

The role of the Left Dorsolateral Prefrontal Cortex in Attentional Bias

Overview

The neurobiology of visual attention involves a dorsal frontal-parietal network involving the dorsolateral prefrontal cortex (DLPFC), the intraparietal sulcus and the frontal eye fields. The DLPFC is also thought to be critically involved in maintaining attention away from behaviourally irrelevant information, and in the establishment of attentional control settings. This chapter probed the involvement of the left DLPFC in attentional bias by increasing or decreasing its cortical excitability via tDCS and then analysing these effects following an induced attentional bias towards the colour green. It was found that anodal tDCS over the left DLPFC appears to increase the amount of cognitive control over attentional bias-related items when behaviourally irrelevant. Cathodal tDCS on the other hand appears to lessen the overall effect of the induced attentional bias – potentially by reducing the influence of top-down modulated attentional control settings thus preventing the development of a control setting favouring green items. These results suggest a causal role of the left DLPFC in the cognitive mechanisms that underlie attentional bias.

6.1 Introduction

So far this thesis has examined attentional biases from a non-clinical perspective, free from social, emotional, neurochemical and population confounds. These experiments have led to the discovery that it is relatively easy to induce an attentional bias towards an arbitrary stimulus in well-educated, healthy participants. Green stimuli do not elicit an emotional response that we are aware of and no natural bias towards green stimuli exists. It is also highly unlikely that participants are relying on well-established long-term memories relating to the perception of green objects. Investigating the neurobiology of this form of rapidly induced attentional bias will therefore allow for the first investigation of the neurobiology of the cognitive basis and cognitive control of attentional bias.

Evidence from neuroimaging studies suggests that the DLPFC plays a role in controlling the effects of incoming information in individuals with pathological attentional biases. Bishop, Duncan, Brett and Lawrence (2004) found that highly anxious individuals have a reduction in DLPFC (and increase in amygdala) activity when confronted with threat-related images compared to those with low state anxiety (Bishop, Duncan, & Lawrence, 2004). This suggests highly anxious individuals are able to exert less control over their threat-related attentional bias. Reduced DLPFC functioning may also be a key feature of anxiety since it allows for less control over amygdala activation. Similar results are found in addicted populations. Hester and Garavan (2009) discovered that cocaine addicts with reduced PFC activity were able to exert less control over irrelevant cocaine-related information than addicts with higher PFC activity, suggesting a key role of the DLPFC in exerting authoritative control over the environment. A DLPFC-mediated lack of control over irrelevant, bias-related objects may account for the behavioural effects of attentional bias. Directly manipulating the activity of the DLPFC during a task involving irrelevant bias-related items may therefore manipulate the amount of control the DLPFC is able to exert over these items, altering the extent to which they affect behaviour.

Although the DLPFC in general appears to play an important role in visual selection, attention and cognitive control, there is also distinct laterality between the right and left DLPFCs. d'Alfonso, van

Honk, Hermans, Postme and de Haan (2000) found via a pictorial Stroop task, that offline repetitive transcranial magnetic stimulation (rTMS) over the right DLPFC applied for 15 minutes prior to a task appeared to increase attention towards angry faces, whereas the same stimulation (applied in a separate session on a different day) over left DLPFC had the opposite effect. d'Alfonso et al. (2000) explain this finding in terms of motivational behaviour towards or away from negative images, however it is equally possible that the rTMS was having differential effects on the amount of cognitive control participants had over the emotive stimuli. Ordinarily, angry faces capture attention (van Honk et al., 1998), most likely due to potential threats associated with negative moods. Stimulation over right DLPFC would have resulted in an inability for this region to be activated, resulting in the left DLPFC being unmodulated by input from the right DLPFC. This could cause an increase in cognitive control and thus decrease visual attention towards the angry faces since the faces were task-irrelevant. Moreover, a dissociation between right and left DLPFC activity and the kinds of attentional control has been observed (Milham, Banich, & Barada, 2003), and increased activity of left DLPFC over right DLPFC is associated with a greater need for attentional control (Liu, Banich, Jacobson, & Tanabe, 2006). Finally, Garavan and colleagues (2002) have found evidence of prefrontal laterality, discovering via a GO/NOGO task that right DLPFC is related to inhibiting responses, whereas left DLPFC is involved in corrections of behaviour following an error. They argue that left DLPFC plays a substantial role in establishing and maintaining an appropriate task 'mental set' that the right DLPFC is not involved in (Garavan et al., 2002).

Using tasks that have been previously established throughout this thesis, the current chapter will therefore investigate the role of the left DLPFC in the cognitive control of attentional biases, via transcranial direct current stimulation (tDCS). While this experiment will compare the effects of anodal versus cathodal tDCS stimulation of left DLPFC, it should be noted that that the effects of tDCS are not restricted to the primary site of stimulation (Ball et al., 2013; Lang et al., 2005). Instead the effects of tDCS stimulation project to other functionally-relevant neural areas (Ellison et al., 2014; Pena-Gomez et al., 2012). Additionally, differential neuronal effects underlie the excitation or

depression of activity whilst tDCS is being applied with respect to the offline phase. Stagg et al. (2009) found that offline anodal tDCS stimulation of 1mA for 10 minutes decreases concentrations of GABA, whereas offline cathodal tDCS stimulation of 1mA for 10 minutes is related to a decrease in glutamate (Stagg et al., 2009). In the DLPFC, glutamate is associated with dopaminergic projections affecting working memory (Durstewitz, Seamans, & Sejnowski, 2000; Noudoost & Moore, 2011; Paspalas & Goldman-Rakic, 2005; Williams & Goldmanrakic, 1995), with an increase of dopamine and glutamate related to heightened working memory capacity and cognitive control (Noudoost & Moore, 2011). It should also be noted that while offline tDCS is related to altered concentrations of neurotransmitters, online tDCS is related to alterations of membrane potential (Stagg et al., 2011; Stagg & Nitsche, 2011).

After reading the information sheet to induce an attentional bias towards green items, participants will complete the shape change detection task while receiving either anodal, cathodal or sham tDCS stimulation. Since anodal tDCS raises the excitability of underlying neurons, and cathodal decreases the excitability of underlying neurons (Nitsche & Paulus, 2000), it is assumed that anodal tDCS will raise the activation of the left DLPFC. This is predicted to raise the amount of cognitive control participants have over the bias-related distraction. Cathodal tDCS will lower the activation of left DLPFC. In this group, it is predicted that they will be able to exert less cognitive control over the task and irrelevant green shapes will cause greater distraction. Finally, as sham tDCS involves no stimulation, participants in this group should mirror the effects previously observed in this task.

6.2 Method

6.2.1 Participants

36 participants (14 male) recruited from staff and students at Durham University took part. Ages ranged from 19-41 (M: 24.72, SD: 5.42). All had normal or corrected to normal vision, no colour blindness (assessed via self-report), and gave informed consent with the approval of Durham University Ethics Advisory Committee. Participants were compensated for their time in the form of Amazon vouchers.

6.2.2 Design

Participants were assigned to one of three groups. All groups received the same information at the start of the experiment and completed the change detection task. All groups were then immediately presented with the shape information sheet and asked to complete the second task whist their left DLPFC was being stimulated via tDCS. Group 1 had the anodal electrode over left DLPFC; Group 2 had the cathodal electrode over left DLPFC; Group 3 received sham stimulation.

6.2.3 Stimuli, Apparatus & Procedure

Participants completed a first change detection task. Stimuli, apparatus and procedure for this initial task were identical to that used in Experiment 1 of Chapter 3 (pages 73-75). Participants were then connected to the tDCS machine before completing a second change detection task. Stimuli, apparatus and procedure for this second task were identical to that used in Experiment 2 of Chapter 3 (pages 81-83). After reading the information sheet about this task, participants were stimulated via tDCS for 5 minutes, and then completed 6 blocks of 60 trials with each block commencing after every 5 minutes. Figure 6.1 shows a schematic of the experimental procedure.

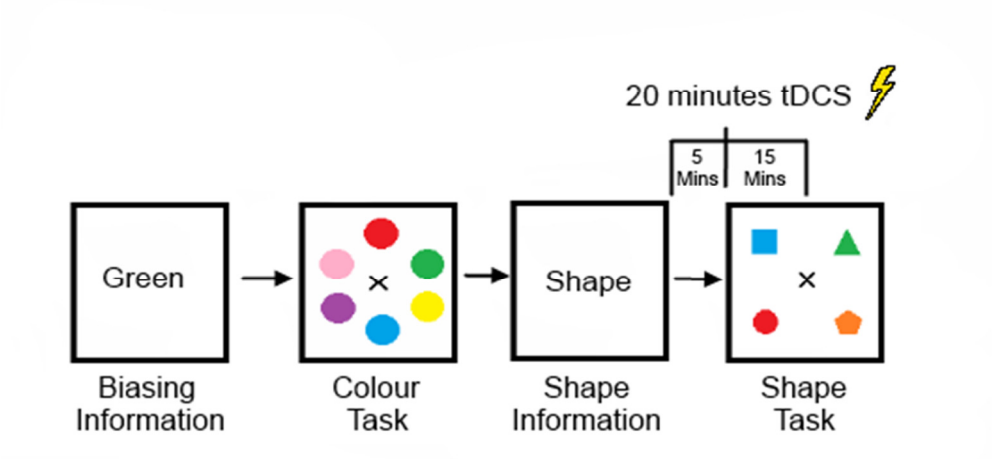

Figure 6.1: Schematic of the tDCS experimental procedure. Participants read the biasing information sheet then complete the colour task. They then read the shape information sheet before being stimulated for tDCS for 20 minutes. After 5 minutes of stimulation, the shape task commences.

6.2.4 Transcranial Direct Current Stimulation

A direct current of 1.5mA was generated using a Magstim Eldith DC stimulator. This was delivered using two rubber electrodes which were placed inside two sponge pouches (7 cm x 5 cm) that had

been soaking in 0.9% physiologically active saline solution (9g salt measured on an electronic scale dissolved in 1 litre of water). The electrodes were held in place using two rubber straps. To increase or decrease excitability of left DLPFC, the relevant Anodal or Cathodal (depending on experimental group) electrode was secured on the scalp over F3 according to the international 10-20 system of electrode placement. This site was chosen following previous research stimulating this area (Wolkenstein & Plewnia, 2013). Following the technique from previous studies (Ball et al., 2013) the reference electrode was placed over the participant's contralateral (right) eye (however, see the discussion for the potential effect this may have had on the right orbitofrontal cortex). For the first 8 seconds of stimulation, the current was gradually increased to 1.5mA then continuously delivered at this intensity for 20 minutes then ramped down over 8 seconds. In the sham condition, this was reduced to 30 seconds so that participants in this group received the initial stimulation sensation and thus were not aware that they were in the sham condition. After 20 minutes, the current was gradually reduced over another 8 seconds to 0 mA.

6.3 Results

6.3.1 Biasing

6.3.1.1 Reaction Time

Mean reaction times for correct trials were entered into a 3 (tDCS: Anodal/Cathodal/Sham) x 3 (Trial: Congruent/Incongruent/Neutral) Mixed Factor ANOVA. tDCS was a between groups factor, Trial was within groups. The ANOVA revealed a significant main effect of Trial: $F(2, 66) = 53.338$, $p < .001$, $r = .669$. Bonferroni corrected pairwise comparisons revealed that reaction times for Congruent Change trials was significantly faster (M: 656.74ms) than reaction times for Incongruent (M: 786.81ms, $p < .001$, $r = .823$) or Neutral (M: 742.86ms, $p < .001$, $r = .783$) trials. Reaction times for Neutral trials were also significantly faster than reaction times for Incongruent change trials ($p < .001$, $r = .597$). No main effect of tDCS was present ($F(2, 33) = 1.340$, $p = .276$, $r = .198$), nor was there a tDCS x Trial interaction ($F(4, 66) = .504$, $p = .733$, $r = .087$). Thus, reaction time data suggests we were successful

in inducing an attentional bias towards the colour green and this inducement did not differ between the three different tDCS groups.

6.3.1.2 d' Scores

Calculated d' scores offering a measurement of participants' sensitivity to accurately detect changes between arrays was also entered into a 3 (tDCS: Anodal/Cathodal/Sham) x 3 (Trial: Congruent/Incongruent/Neutral) Mixed Factor ANOVA. As before, tDCS was a between groups factor, Trial was within groups. There was a significant main effect of Trial: $F(2, 66) = 64.199$, $p < .001$, $r = .702$. Pairwise comparisons following a Bonferroni correction revealed that d' scores for Congruent change trials was significantly higher (M: 2.771) than d' scores for both Incongruent (M: 1.728, $p < .001$, $r = .869$) and Neutral (M: 1.963, $p < .001$, $r = .771$) change trials. Furthermore, d' scores for Neutral Change trials were significantly higher than d' scores of Incongruent Change trials ($p = .002$, $r = .552$). As with the reaction time results, no main effect of tDCS was present ($F(2, 33) = .568$, $p = .562$, $r = .130$), and there was no tDCS x Trial interaction ($F(4, 66) = .847$, $p = .501$, $r = .113$). Thus, the d' score results reflect those of previous experiments – participants are significantly more sensitive at detecting when a green object changes in an array, and also wen a green object is present but does not change, this reduces sensitivity in accurately detecting changes elsewhere. These results are evident across all groups, thus we were successful in inducing an attentional bias and there appear to be no inherent differences in this inducement in our three tDCS groups before tDCS was applied.

6.3.1.3 Criterion

Finally, Criterion scores which offer a measurement of responder bias were calculated and also entered into a 3 (tDCS: Anodal/Cathodal/Sham) x 3 (Trial: Congruent/Incongruent/Neutral) Mixed Factor ANOVA. As before, tDCS was a between groups factor, Trial was within groups. There was a significant main effect of Trial: $F(2, 66) = 73.467$, $p < .001$, $r = .726$. Bonferroni corrected pairwise comparisons revealed that Criterion scores of Congruent Change trials were significantly lower (M: .013) than Criterion scores of both Incongruent (M: .548, $p < .001$, $r = .938$) and Neutral Change (M:

.429, p <.001, r = .801) trials. Criterion scores of Incongruent Change trials were significantly higher than Criterion scores of Neutral Change trials (p = .001, r = .569). Since a lower Criterion is indicative of more liberal responding (i.e., more likely to report changes than no changes) and vice versa, this suggests that the inducement of an attentional bias towards the colour green caused more liberal responses in trials when a green object changed, and more conservative responses in trials when a green object was present but did not change. Reflecting both the reaction time data and the d' data, there was no main effect of tDCS: F(2, 33) = 1.632, p = .211, r = .217, and no tDCS x Trial interaction: F(4, 66) = .551, p = .699, r = .091. Thus, there were no natural biases between the groups before tDCS was applied to left DLPFC towards responding more conservatively or more liberally.

6.3.2 Shape

6.3.2.1 Reaction Time

Overall reaction times were entered into a 3 (tDCS: Anodal/Cathodal/Sham) x 2 (Bias: Green Present/Green Absent) x 2 (Trial: Change/No Change) Mixed Factor ANOVA. tDCS was a between groups factor, Bias and Trial were both within groups factor. There was a significant main effect of tDCS: F(2, 33) = 6.531, p = .004, r = .406. Bonferroni corrected pairwise comparisons revealed that participants in the Sham group were significantly slower (M: 772.676ms, SD: 157.927ms) than those in the Anodal (M: 587.876ms, SD: 116.897ms, p = .002, r = .540) and Cathodal (M: 629.516ms, SD: 112.875ms, p = .012, r = .497) groups. Secondly, there was a significant main effect of Trial: F(1, 33) = 6.317, p = .017, r = .401. As expected, reaction times for Change trials were significantly faster (M: 647.300ms, SD: 165.977ms) than No Change trials (M: 679.413ms, SD: 149.013ms). A main effect of Bias was also present: F(1, 33) = 12.214, p = .001, r = .520. Overall reaction times when a green shape was present were significantly slower (M: 673.061ms, SD: 171.143ms) than when a green shape was absent (M: 653.651ms, SD: 153.207ms).

Finally, Bias and tDCS interacted: F(2, 33) = 16.089, p<.001, r = .572. To elucidate, the effect of the presence of a green shape on reaction time was examined for each tDCS group separately via three paired-samples t-tests (Green Shape Present/Green Shape Absent). The t-test for the Anodal group

was non-significant: t(23) = -.607, p = .550, r = .126, as was the t-test for the Cathodal group: t(23) = -.213, p = .833, r = .044. However, the t-test for the Sham group was significant: t(23) = 6.888, p<.001, r = .829. Here, reaction times when a green shape was present were significantly slower (M: 804.6544ms, SD: 190.269ms) than when no green shape was present (M: 740.6985, SD: 167.265ms). These are seen in Figure 6.2.

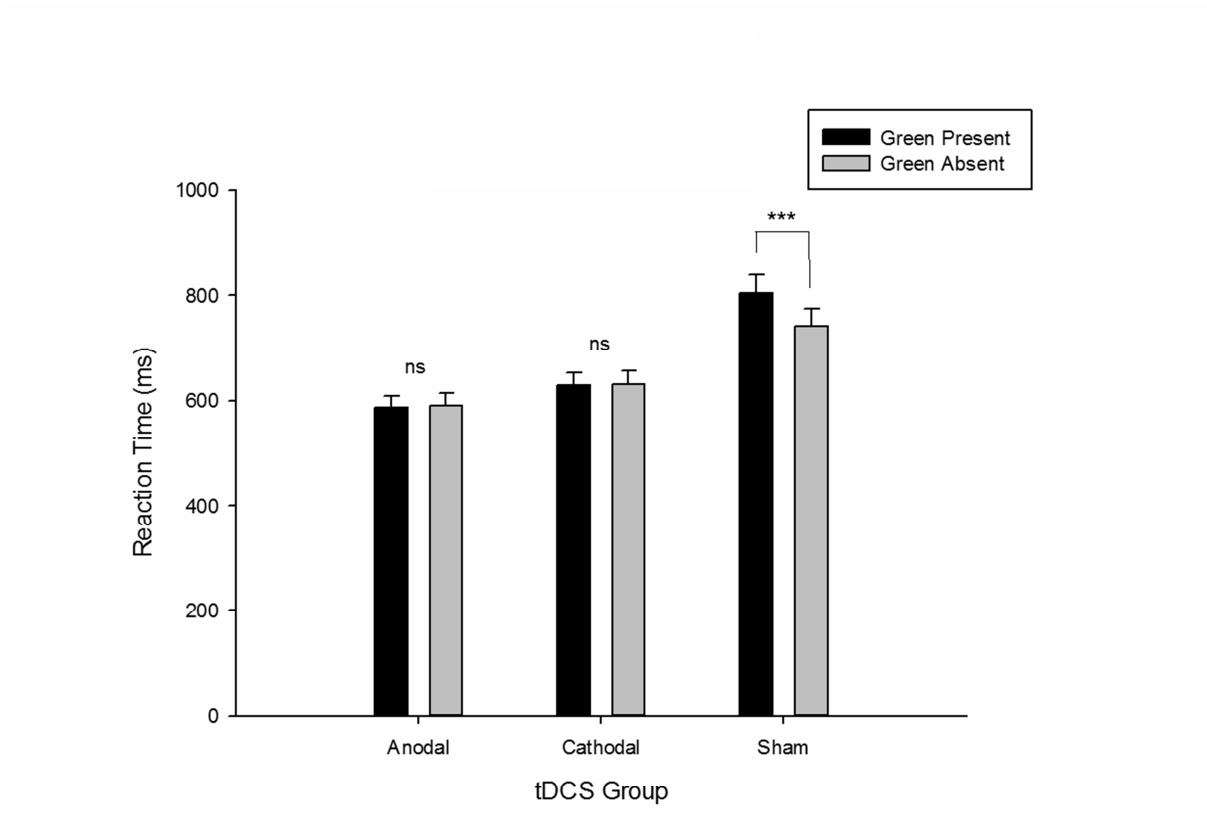

Figure 6.2: Differences in reaction time in the Shape task observed across all tDCS groups. There is no difference in reaction time when a green shape is present in the Anodal or Cathodal tDCS group. However, the Sham group were significantly slower when a green shape was present. *Note*, *** p<.001

6.3.2.1.1 Online vs Offline tDCS: Reaction Time

To assess any possible differences in reaction time between online tDCS and offline tDCS, the ANOVA was re-run, with an extra within subjects' factor added in. Here, mean reaction times were entered into a 3 (tDCS: Anodal/Cathodal/Sham) x 2 (Bias: Green Present/Green Absent) x 2 (Trial: Change/No Change) x 2 (Stimulation: Online/Offline) Mixed Factor ANOVA. A main effect of Stimulation was observed: F(1,33) = 29.494, p<.001, r = .687. Reaction times in Online trials were significantly slower (M: 687.407ms, SD: 170.449ms) than reaction times in Offline trials (M:

639.304ms, SD: 147.701ms). However, since this did not interact with any other variable, this could reflect practice or familiarity (Stimulation x tDCS: F(2, 33) = 2.667, p = .084, r = .273; Stimulation x Bias: F(1, 33) = .006, p = .938, r = .013; Stimulation x Trial: F(1, 33) = .082, = .777, r = .050).

6.3.2.2 d' Scores

Calculated d' scores for the overall experiment were entered into a 3 (tDCS: Anodal/Cathodal/Sham) x 2 (Bias: Green Present/Green Absent) Mixed Factor ANOVA. tDCS was a between groups factor, Bias was a within groups factor. The application of tDCS had no main effect on overall d' scores: F(2, 33) = .279, p = .758, r = .092. There was also no significant main effect of Bias, however the p-value and effect size suggests that it is approaching significance: F(1, 33) = 3.441, p = .073, r = .307, with some evidence of a trend of d' scores in Green Present trials being lower (M: 1.884, SD: .462) than Green Absent trials (M: 1.979, SD: .281). There was, however, a significant interaction between tDCS and Bias: F(2, 33) = 4.885, p = .014, r = .359. This was examined via three paired t-tests; each examined the difference in d' scores between Green Present and Green Absent trials separately for each tDCS group. The t-test for the Anodal group was non-significant: t(11) = .469, p = .648, r = .140, as was the t-test for the Cathodal group: t(11) = -.215, p = .832, r = .065. However, the t-test for the Sham group was significant: t(11) = -4.515, p = .001, r = .806. Here, d' scores for Green Present trials were significantly lower (M: 1.806, SD: .393) than those of Green Absent trials (M: 2.125, SD: .422). Since a lower d' score is indicative of reduced perceptual sensitivity, this shows that our Sham tDCS group showed the same pattern of behaviour as found in previous chapters – when participants have an induced attentional bias towards a type of stimulus, objects that share this property cause a reduction in sensitivity when other changes occur. However, it appears as if the application of tDCS over the left DLPFC negates this effect. These effects can be seen in Figure 3.6.

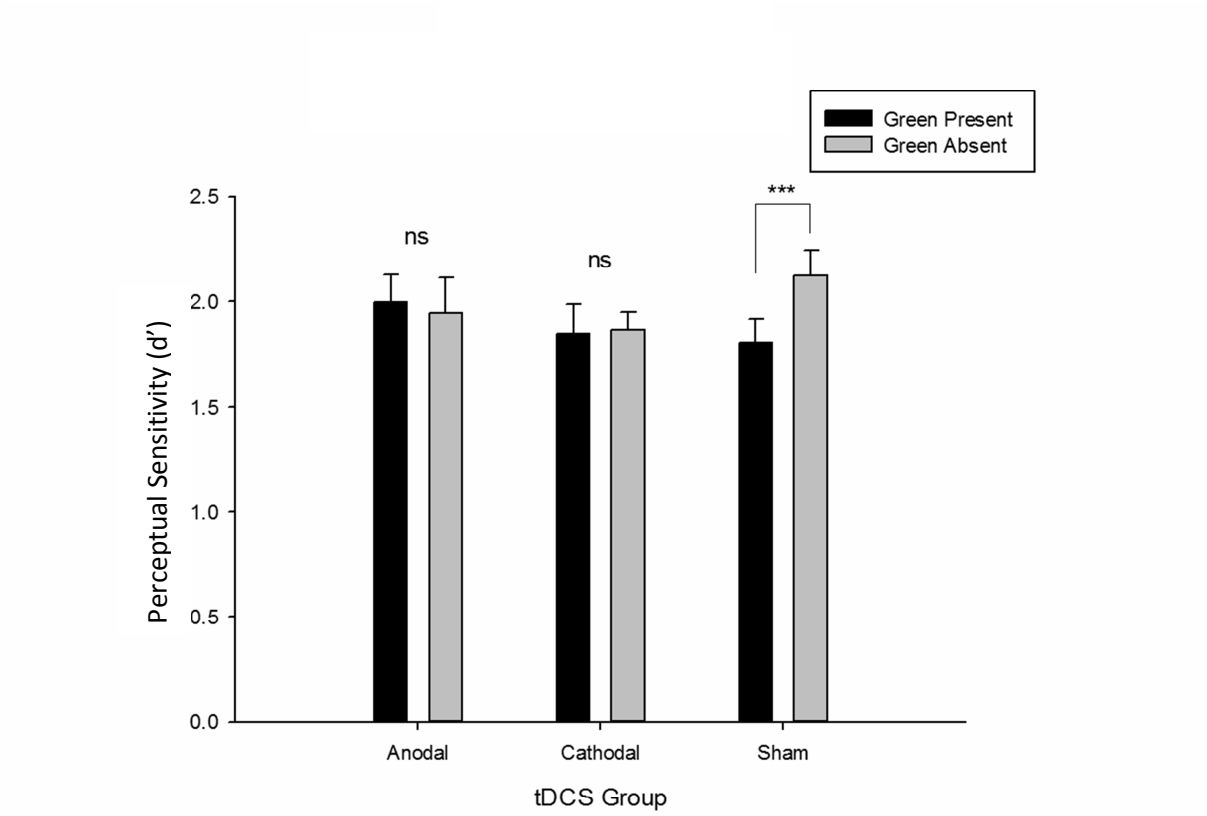

Figure 6.3: Differences in perceptual sensitivity (d') in the Shape task observed across all tDCS groups. There is no difference in perceptual sensitivity when a green shape is present in the Anodal or Cathodal tDCS group. However, the Sham group were significantly less sensitive at detecting changes when a green shape was present. *Note*, *** p<.001

6.3.2.2.1 Online vs Offline tDCS: d' Scores

To assess differences in d' scores between online tDCS and offline tDCS, the ANOVA was re-run, with an extra within subjects Factor of Stimulation. Thus, a 3 (tDCS: Anodal/Cathodal/Sham) x 2 (Bias: Green Present/Green Absent) x 2 (Stimulation: Online/Offline) Mixed Factor ANOVA was run.

An interaction between Stimulation and tDCS verged on significance: $F(2, 33) = 3.262$, $p = .051$, $r = .300$. Since the Anodal and Cathodal groups were receiving real tDCS in Online trials yet the Sham group were not, there was sufficient cause to explore this further. Thus, three paired t-tests examined the difference of d' scores in Online versus Offline trials separately for each tDCS group. The t-test for the Anodal group was non-significant: $t(23) = .465$, $p = .646$, $r = .097$. However, the t-test for the Cathodal group was significant: $t(23) = -3.444$, $p = .002$, $r = .583$. Here, d' scores in Online trials were significantly lower (M: 1.767, SD: .505) than in Offline trials (M: 2.041, SD: .415). This

suggests that Cathodal tDCS over the left DLPFC reduces perceptual sensitivity. Finally as expected, the t-test for the Sham group was non-significant: t(23) = -1.080, p = .291, r = .230. This suggests that perceptual sensitivity does not naturally increase over the course of the experiment. In other words, there is no evidence that familiarity with the task improves participants' ability to detect change.

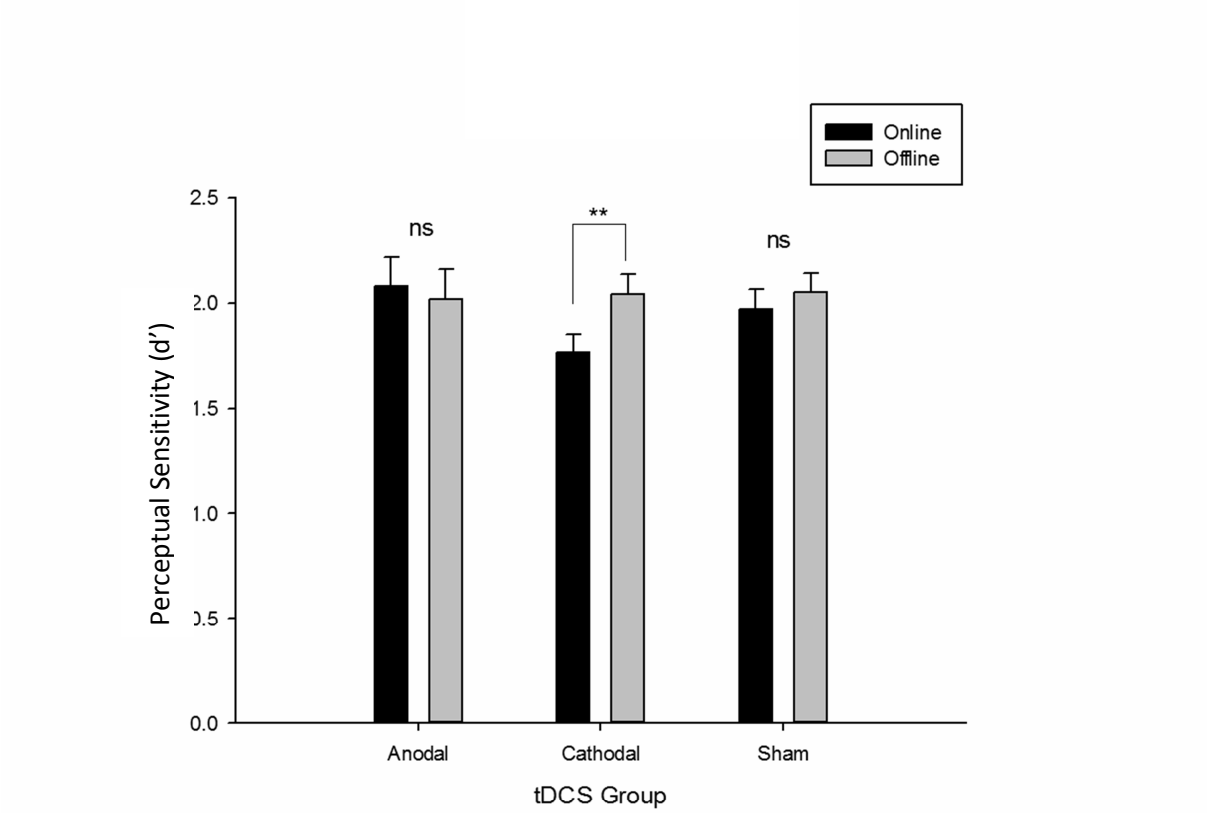

Figure 6.4: Differences in perceptual sensitivity (d') in the Shape task observed in Online and Offline trials. There is no difference in perceptual sensitivity in Online compared to Offline trials for the Anodal or Sham tDCS groups. However, the Cathodal group were significantly less sensitive at detecting changes in Online compared to Offline trials. *Note*, ** p<.005

6.3.2.3 Criterion

Calculated Criterion scores were entered into a 3 (tDCS: Anodal/Cathodal/Sham) x 2 (Bias: Green Present/Green Absent) Mixed Factor ANOVA. tDCS was a between groups factor, Bias was a within groups factor. No main effect of tDCS group was observed: F(2, 33) = .499, p = .611, r = .122. However, there was a main effect of Bias: F(1, 33) = 10.481, p = .003, r = .491. Here, Criterion Scores in Bias Present trials were significantly higher (M: .269, SD: .350) than in Bias Absent trials (M: .201, SD: .367). Since a higher criterion is indicative of a shift towards more conservative responding, it

appear as if the presence of a green shape in the task caused participants to become more conservative when deciding if a change occurred in an array or not.

Finally, there was a significant interaction between Bias and tDCS: $F(2, 33) = 21.681$, $p < .001$, $r = .630$. This was further investigated via three paired t-tests. Each examined the differences in Criterion scores between Bias Present and Bias Absent trials separately for each tDCS group. The t-test for the Anodal group was non-significant: $t(11) = -1.580$, $p = .142$, $r = .430$, as was the t-test for the Cathodal group: $t(11) = .302$, $p = .768$, $r = .163$. However, the t-test for the Sham group was significant: $t(11) = 7.245$, $p < .001$, $r = .909$. Here, Criterion Scores in Bias Present trials were significantly higher (M: .362, SD: .444) than in Bias Absent trials (M: .102, SD: .479). Therefore, only for participants in the Sham group did the presence of an irrelevant green shape cause participants to become more conservative with their responses (i.e., more likely to report no change and less likely to report a change).

6.3.2.3.1 Online vs Offline tDCS: Criterion

Finally, to assess any differences in Criterion between online tDCS and offline tDCS, the ANOVA was re-run, with a within subjects factor added. This resulted in a 3 (tDCS: Anodal/Cathodal/Sham) x 2 (Bias: Green Present/Green Absent) x 2 (Stimulation: Online/Offline) Mixed Factor ANOVA. tDCS was a between groups factor, Bias and Stimulation were within groups. A main effect of Stimulation was observed: $F(1, 33) = 6.806$, $p = .014$, $r = .399$. Criterion scores in Online trials were significantly higher (M: .309, SD: .399) than in Offline trials (M: .190, SD: .428). Stimulation did not interact with tDCS ($F(2, 33) = 1.379$, $p = .266$, $r = .200$), Bias ($F(1, 33) = .003$, $p = .954$, $r = .001$) or Bias x tDCS ($F(2, 33) = 1.669$, $p = .204$, $r = .219$). A main effect of Bias was also observed: $F(1, 33) = 17.169$, $p < .001$, $r = .585$. Criterion scores of Green Present trials were significantly higher (M: .295, SD: .406) than Green Absent trials (M: .203, SD: .421). This suggests that when an irrelevant bias-related item is present in a change detection task, participants shift their internal biases and become more conservative with how they respond, reporting fewer Changes and more No Changes.

6.4 Discussion

This study investigated the role of the left DLPFC in the cognitive control of attentional bias using tDCS. Neuromodulation of the left DLPFC was found to affect the cognitive control of attentional bias. The distraction caused by irrelevant green shapes disappeared when the excitability of left DLPFC was increased using anodal tDCS. This suggests that this stimulation increased the amount of cognitive control the left DLPFC has over the attention system orientating towards green stimuli when participants are explicitly aware that colour is completely irrelevant to their current task demands, confirming a causative executive role of this region in cognitively controlling for attentional bias-related distractions; a theoretical standpoint supported by previous studies (Fassbender et al., 2004; Garavan et al., 2002; Spreng, Sepulcre, Turner, Stevens, & Schacter, 2013).

Reaction times when an irrelevant green shape is present in an array are identical to when no green shape is present. In the sham group, an irrelevant green shape caused a significant slowing of reaction times – mirroring results of previous chapters. Such responses towards bias-related stimuli have been consistently observed via the dot probe paradigm (Macleod et al., 1986). Here, dots congruent to bias-related stimuli are detected faster than dots that are not due to attention being disengaged then reengaged in the latter condition (Ehrman et al., 2002; Townshend & Duka, 2001). Anodal tDCS has negated this effect, making it appear as if the ordinarily biased green feature did not capture attention. Thus, decreasing the threshold at which left DLPFC is activated enhances the extent to which left DLPFC can exert control over the orienting of attention meaning irrelevant items that would normally capture attention can be more successfully ignored. This is supported by the association between decreased DLPFC activity and a lack of control over bias-related stimuli (Bishop et al., 2004; Bishop, 2009; Hester & Garavan, 2009). Moreover, patients with major depressive disorder exhibit higher left DLPFC activity in response to negative images than healthy controls, suggesting more involvement of this area to control for their negative-affect attentional biases (Kerestes et al., 2012).

Ordinarily, the left DLPFC is believed to play a directive role in orienting and allocating attention (Corbetta & Shulman, 2002; Liu et al., 2006; MacDonald et al., 2000). Thus, the left DLPFC is in direct communication with the attention network (including the IPS and FEF), and can direct this network in a top-down manner to allocate higher processing priority to task-congruent information (Belopolsky & Theeuwes, 2010; Corbetta et al., 2002; Leber & Egeth, 2006b; Reynolds & Chelazzi, 2004). With an attentional bias, it appears as if the DLPFC is unable to exert enough control over the attention network, thus bias-related items capture and hold attention even when behaviourally inconsistent (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Faunce, 2002; Field & Cox, 2008).

However, there exists uncertainty about the nature of this lack of control in attentional bias. The behavioural effects of attentional bias-related items (the ability of bias-related items to cause differential effects on behaviour) may stem from an overall lack of control since the neural responses triggered by often highly-emotive bias-related stimuli are too strong for the DLPFC to control (Janes et al., 2010). However, this seems unlikely since we have shown multiple times that it is possible to induce a highly robust attentional bias in healthy individuals towards a completely arbitrary and non-emotive stimulus. Instead, it is more likely that an attentional bias involves a persistent alteration to an attentional setting (Bacon & Egeth, 1994; Leber & Egeth, 2006a, 2006b; Leber et al., 2009), which is consistently reinforced by long-term memory representations (Carlisle et al., 2011) and contextual cuing (Cosman & Vecera, 2013). Here, the contextual cues would cause the DLPFC to allocate higher priority to bias-related items, since the cues would suggest that bias-related items were task-relevant and hence behaviourally congruent. This can occur with both pathological stimuli (Jones et al., 2006) and neutral, arbitrary stimuli as has been found in this thesis.

This chapter not only provides evidence that anodal tDCS increased the amount of cognitive control the left DLPFC has over the attention system, but also suggests that such neuromodulation increases the overall efficiency of the attention system. This allows information to be attended to, processed,

and decided on faster than normal. This is primarily evident in the difference in overall reaction times between the anodal tDCS group and the sham group. As discussed, there is a vast amount of evidence supporting the role of the DLPFC as part of an executive system that controls what information should be attended to in a top-down manner (Corbetta & Shulman, 2002; Reynolds & Chelazzi, 2004). It therefore seems that increasing the excitability of the left DLPFC allows this authoritative role to occur more efficiently – speeding up the rate at which incoming information is perceived and processed.

A further effect of anodal tDCS over left DLPFC is of participants' sensitivity to detect change. Ordinarily following an induced attentional bias towards the colour green, irrelevant green shapes reduce sensitivity to detect changes elsewhere. This pattern is replicated in the sham tDCS group. However, anodal tDCS over left DLPFC has negated this. There was no difference in sensitivity to detect changes between Green Present and Green Absent trials for the anodal tDCS group, again suggesting that the biasing properties of green shapes had no effect on behaviour when the excitability of the left DLPFC was increased. This result complements the reaction time data, further potentiating that increasing the excitability of left DLPFC increases cognitive control (Spreng et al., 2013). As such, when participants are explicitly aware that colour is task-irrelevant, this allows the left DLPFC to exert greater control over the effects of colour. Objects related to this visual feature in the current task were then more successfully ignored – speeding reaction times and negating any distracting effects resulting from these irrelevant properties.

These findings are consistent with a previous study that used tDCS to modulate the effect of bias-related stimuli in depressed patients (Wolkenstein & Plewnia, 2013). Wolkenstein and Plewnia (2013) studied 22 patients with major depressive disorder and examined their response towards emotional or non-emotional images in a working memory task. Anodal tDCS over left DLPFC significantly enhanced working memory abilities of both patients and controls. Moreover, this improvement in the cognitive control over emotive stimuli normally observed in patients with major

depressive disorders was so remarked that it abolished their negative-emotive attentional biases. It was argued that the tDCS improved participants' working memory and cognitive control abilities (Botvinick et al., 2001; Botvinick et al., 2004; Fregni et al., 2007) allowing them to more successfully ignore the emotive images and focus on the task-relevant aspects of the experiment.

In the current experiment, anodal tDCS increased the amount of cognitive control participants had in the shape change detection experiment, enabling more successful suppression of irrelevant colours. This is evidenced by the findings that anodal tDCS negated the effect observed in the sham group (and throughout this thesis) that the presence of an irrelevant bias-coloured shape reduced perceptual sensitivity to detect change. Importantly, the current study also clarifies the effects observed in Wolkenstein and Plewnia (2013) whose research is somewhat muddied by the issue that over half of their sample of patients were taking a wide variety of anti-depressive and anti-anxiety medications – many of which alter neurochemistry (Carr & Lucki, 2011; Millan, 2004; Musazzi, Racagni, & Popoli, 2011; Skolnick, 1999; Willner, 1985). Similarly, Boggio, Zighi and Fregni (2009) found that anodal tDCS over left DLPFC decreased the emotional discomfort participants had when viewing images of other humans in pain (Boggio, Zaghi, & Fregni, 2009). These findings were likely due to left DLPFC exerting greater control over the environment, inhibiting the extent to which other regions associated with pain perception – such as the amygdala or ACC – were activated in order to minimise negative emotional discomfort. This again supports the role of the left DLPFC as an executive region which exerts control over vast networks of neural activity.

The application of cathodal tDCS over left DLPFC also appears to have negated the biasing effects of irrelevant green shapes; however the underlying reasons for this are arguably distinct from the effects of anodal tDCS. Cathodal tDCS decreases the excitability of underlying neurons (Nitsche, Boggio, Fregni, & Pascual-Leone, 2009; Nitsche et al., 2008; Nitsche & Paulus, 2000). It was originally predicted that this would result in reduced cognitive control over the attention system, suggesting that the biasing effects of the irrelevant green shapes following an induced attentional bias towards

green would be exacerbated in the cathodal group. However, reaction times in the cathodal group suggest that green shapes were not more distracting than previously observed. Instead, reaction times were on a whole faster than those of the sham group, and – more importantly – there was no difference in reaction times of Green Present and Green Absent trials. Since the application of cathodal tDCS over left DLPFC reduces excitability of neurons in left DLPFC and thus reduces the effects that this region has over the attention network, it is possible that reducing the involvement of left DLPFC reduces the overall effects of attentional biases. In other words, the application of cathodal tDCS may have reduced or potentially even removed the initial attentional bias, thus bias-related items do not cause a behavioural effect because there is little or no bias present to begin with. This may be achieved by significantly reducing the influence of top-down controlled attentional control settings, preventing the establishment of an attentional setting towards a certain category of stimuli (Folk et al., 1992; Leber & Egeth, 2006b).

When the excitability of left DLPFC is decreased, it appears as if these attentional settings are effectively bypassed, meaning that bottom-up influences on the priority map carry more weight than top-down influences. As all of the shapes in the shape task are of the same visual angle, and all of the colours are of the same luminance there is no difference between their bottom-up signals and thus, all are equally represented on the priority map. These effects are evident in the reaction times and perceptual sensitivity of participants in the cathodal tDCS group. In the same way that the anodal tDCS group showed no reduction in sensitivity when a green shape was present, cathodal tDCS over left DLPFC has also removed the effect of an irrelevant green shape on reducing perceptual sensitivity. Again, this is believed to be due to cathodal tDCS effectively removing the effects of attentional settings, meaning items are selected for further processing based purely on their bottom-up characteristics. Therefore, reducing the excitability of the left DLPFC essentially reduces the effects of executing top-down control over visual attention, rendering the induced bias inconsequential and removing its behavioural effects.

This explanation is supported by findings relating DLPFC activation to implementing an attentional set. Banich et al. (2000) discovered via a Stroop-type task with fMRI that prefrontal regions, rather than the ACC, appeared to play a greater role in implementing an attentional set, and that activation in prefrontal regions was higher when the attentional set was more challenging to impose (Banich et al., 2000). Likewise, Luks, Simpson, Feiwell and Miller (2002), and Luks, Simpson, Dale and Hough (2007) found using two different experimental paradigms that DLPFC was associated with holding behavioural goals in working memory, and directing the necessary neural networks to processing information that met with those behavioural goals (Luks et al., 2007; Luks, Simpson, Feiwell, & Miller, 2002). This is synonymous with implementing an attentional setting and prioritising information compatible with the set. However, these findings are merely correlative and are unable to attribute any causal link between the DLPFC and the implementation of an attentional setting to prioritise incoming information in a top-down manner. The use of neural stimulation has overcome this, finding that decreasing the excitability of the left DLPFC appears to have rendered the effects of an attentional setting towards green items following an induced attentional bias (as observed in the sham group) negligible. Thus, the current experiment finds evidence of a causal link between the left DLPFC and the implementation of a preparatory attentional setting that alters the effects of top-down modulation on visual attention.

Further evidence that the similar effect of anodal and cathodal tDCS on behaviour are caused by different mechanisms is observed in the difference between online and offline performance. In the experiment, tDCS was applied to the scalp for 5 minutes before any blocks of shape change detection trials began. After this, a new block of trials began after every 5 minutes until participants had completed 6 blocks. Participants in real tDCS groups received 20 minutes of stimulation, thus receiving online tDCS for the first three blocks, and offline tDCS for the final three blocks. This design presents the opportunity compare online with offline tDCS effects.

As expected, comparing behaviour in the first three compared to the second three blocks of trials had no effect for the Sham group. However, it appears that online versus offline tDCS has differing effects for the cathodal compared to anodal groups. This difference extends only to differences in perceptual sensitivity. Here, participants in the cathodal group were more sensitive at detecting changes overall during offline blocks than online blocks. This supports our theory that cathodal tDCS reduces the ability of the left DLPFC to implement an attentional control setting, resulting in less top-down attentional control over incoming visual information in online trials. This appears to have rendered the attention system less efficient overall whilst this disruption is taking place, and alleviating the issue when the interference is tuned off. Such online versus offline effects were not observed in the anodal group, suggesting that the increase in excitability and the knock-on effect this has on the attention network as a whole, is a more gradual effect.

Offline tDCS stimulation is related to altered concentrations of neurotransmitters, whereas online tDCS is related to alterations of membrane potential (Stagg et al., 2011; Stagg & Nitsche, 2011). In the current task, hyperpolarisation of DLPFC appears to have caused a decrease in perceptual sensitivity compared to the effects of altered concentrations of neurotransmitters. Offline cathodal tDCS decreases concentrations of glutamate (Stagg et al., 2009). An increase of glutamate is associated with increased working memory capacity and cognitive control (Durstewitz et al., 2000; Noudoost & Moore, 2011; Williams & Goldmanrakic, 1995). Here, it was found that this potential alteration of glutamate did not negatively affect the cognitive control over irrelevant bias-related information. This further supports the theory that cathodal tDCS over the left DLPFC has eradicated the attentional control settings favouring bias-related visual information – believed to be the cognitive foundation of attentional biases. This is because a reduction in glutamate – associated with a reduction in cognitive control – did not result in a reduction of perceptual sensitivity when an item relating to an attentional bias was present but irrelevant, suggesting that there was no attentional bias present and no need to cognitively control for distractions relating to the bias following cathodal tDCS.

Further support stems from Ball et al. (2013), who found firstly that only cathodal, not anodal, tDCS to the right posterior parietal cortex had an effect on visual search, and that this effect of cathodal stimulation was restricted to experimental blocks occurring concurrently or immediately following the stimulation. This finding not only highlights the differing effects that anodal versus cathodal stimulations can have, but also that these effects may differ in online versus offline experimental blocks. In the current experiment, this is observed in the differences of perceptual sensitivity between online and offline experimental blocks, which was observed only for the group receiving cathodal stimulation. It suggests that the implementation of an attentional set – which is arguably disrupted by cathodal stimulation to the left DLPFC – is dependent on the current membrane potential of underlying neurones but not on decreased levels of glutamate.

While the current study appears to provide strong evidence of a neural region causally relating to the implementation and cognitive control of a current attentional set, caution must be made when directly attributing these findings to the left DLPFC. Although the current study stimulated the left DLPFC anodally and cathodally – and included a sham condition as a control – the location of the reference electrode during stimulation must also be taken into consideration. Following previous studies (Ball et al., 2013; Fecteau, Knoch, et al., 2007; Fecteau, Pascual-Leone, et al., 2007; Fregni et al., 2005; Fregni, Boggio, Nitsche, Rigonatti, & Pascual-Leone, 2006; Knoch et al., 2008), the chosen site for the reference electrode was above the contralateral eye. As the primary electrode was placed over the left DLPFC, this meant that the reference electrode was placed above the right eye. However, it is important to note that tDCS works by passing a current between the two electrodes, meaning that while one electrode is named the “reference” electrode it is still actively involved in the stimulation. The brain region under the right eye is the right orbitofrontal cortex (rOFC), thus when the left DLPFC was being anodally stimulated, the rOFC was being cathodally stimulated and vice versa.

There are strong links between the OFC and reward-based decision making (Bolla et al., 2003; Rolls, 1999, 2000; Volkow & Fowler, 2000). Specifically, evidence suggests that the OFC is required in converging information from multiple sources – including sensory and cognitive – to form a goal-value that a decision is then made based from (Camus et al., 2009; Padoa-Schioppa & Assad, 2006; Rangel, Camerer, & Montague, 2008; Wallis, 2007; Wallis & Miller, 2003). This suggests that the OFC receives input from the DLPFC as part of the multisensory information that converges here. tDCS over the DLPFC will then not only affect the information that is sent to the OFC, but stimulation of the OFC will have an effect on the decision making that results from this. Specifically, decreasing the excitability of the OFC should result in poorer decision making because the area is less able to receive and process the multisensory and cognitive information sent to it (Camus et al., 2009).

In the current study, this multisensory information is the attentional setting informing the attention system in a top-down manner what information to prioritise, as well as the cognitive control input from the DLPFC, stemming from the explicit instructions to ignore colour in the shape task. It is therefore possible that the anodal DLPFC (increasing the cognitive control of the task) alongside cathodal OFC stimulation (decreasing the ability to make decisions from multisensory, affective and cognitive information) magnified the observed effects, meaning that the cognitive control over ignoring colour was amplified because there was less input from the OFC. Similarly, cathodal DLPFC (negating the attentional control setting for green) and anodal OFC stimulation (increasing the ability to make decision from multisensory information) had a magnified effect in the shape task, since the OFC not only received no information of an attentional control setting, but was able to make more behaviourally effective decisions from the information it received – resulting in the increased perceptual sensitivity observed in the cathodal DLPFC group.

Due to the fact that the OFC and DLPFC are anatomically interconnected (Feil et al., 2010), and so DC stimulation of one area may have an effect on the other (Ball et al., 2013; Ellison et al., 2014), it is difficult to state with certainty if the results of the experiment in this chapter stem from DLPFC

stimulation, OFC stimulation or a combination of both. Future studies could address this by studying the effects of both anodal and cathodal tDCS stimulation on the left DLPFC and right OFC regions separately using a non-neural reference electrode and/or a neutral reference site over a region not believed to be involved in visual attention, cognitive control or decision making (though since tDCS is not restricted to the primary site of stimulation, finding an appropriate site may prove difficult).

In conclusion, the current experiments successfully induced an attentional bias towards an arbitrary stimulus in a group of healthy participants before disrupting the involvement of the left DLPFC (and right OFC) via tDCS. Anodal DC stimulation over the left DLPFC increased the amount of executive control participants had over the task, which negated the biasing properties of green shapes observed in the no stimulation group. Cathodal DC stimulation over the left DLPFC however prevented participants from adopting an attentional setting towards green, causing behaviour in the task to be bottom-up modulated with negligible top-down control. Since all shapes were of equal visual angle and all colours were equiluminescent, this resulted in a negation of the effects of the attentional bias, which appears to be under the control of initial top-down attentional settings. Thus, the left DLPFC appears to play a critical role in the initial adoption of attentional control settings, in the establishment of an attentional bias and thus, is involved at the level where top-down information carries more weight on the orienting of visual attention than bottom-up information. Manipulating this region to either prevent the control settings from being adopted or allowing individuals to have greater executive control over incoming information in psychopathological populations may provide an effective avenue for future research into treatment.

Chapter 7
General Discussion

Overview

The five experimental chapters that make up this thesis all probed the cognitive mechanism underlying the development, control and neurobiology of attentional bias. All chapters examined these issues in different – but related – ways. This chapter collates these separate experimental approaches to form a cohesive whole. Attentional bias was examined from a cognitive perspective using controlled samples of healthy participants with comparable executive functioning using a novel one-shot change detection task. It was found that altered attentional control settings appear to be the cognitive basis of attentional bias. Although not examined specifically, these attentional control settings could relate to a persistent selection of a stimulus-specific form of Feature Search Mode. It is probable that population-specific behaviours are then formed on top of these altered settings. This suggests that the additional emotional processing that occurs alongside the majority of attentional biases merely strengthens the bias, but is not responsible for the initial formation of the bias. The left dorsolateral prefrontal cortex appears to be involved in attentional bias in a twofold way. Firstly, it plays a causal role in the formation of these attentional control settings and secondly, once the settings have been established it plays a causal role in the executive control over bias-related information when task-irrelevant. These findings are the first to explicitly demonstrate the purely cognitive aspects of attentional bias and are therefore attributable to all populations displaying the phenomena. This can therefore transfer back to the more traditional abnormal investigations of attentional bias, potentially providing an avenue to be investigated for treatment purposes.

The aim of this thesis was to take a novel approach to the investigation of attentional bias. Previous research has only examined the development and behavioural effects of attentional bias from within various abnormal populations. These have supplied a good understanding of how maladaptive biases impact various psychological disorders, but a poor understanding of the shared, cognitive aspects of attentional bias. This thesis addressed this by examining attentional bias from a cognitive perspective. A more suitable testing paradigm alongside a normative sample of participants was employed, before the neural substrates involved in the cognitive control of attentional bias were probed. These experiments have offered a bridge between the cognitive literature on the orienting of visual attention and the abnormal literature on maladaptive attentional biases which paves the way for more cross-communication between these subsets of psychology. Taken together, this suite of experiments has succeeded in enhancing our understanding of the mechanisms involved when visual attention is biased.

The first objective was to investigate if a cognitive basis of attentional bias – theorised in the General Introduction – exists. It was argued that if an attentional bias can be induced in a healthy sample towards an arbitrary stimulus, this would provide strong evidence that the driving force behind attentional biases is cognitive in nature and does not rely on strong emotional attachments or reward-based neural involvement that is present in the various populations who hold maladaptive biases. That is not to say that once the cognitive basis exists it cannot be reinforced by emotion/reward/learned associations, but just that the initial development of the cognitive basis does not depend on these reinforcements. Using this assumption, this thesis followed the initial objective of a 2005 paper by Yaxely and Zwaan and provided a sample of healthy young adults with a single information sheet about the nature of a task before examining how this information sheet affected visual attention. However, whereas Yaxely and Zwaan used a paradigm offering only reaction time data, this thesis utilised the one-shot change-detection paradigm (Beck et al., 2006; Beck et al., 2001) which allowed for the calculation of perceptual sensitivity and responder bias. Moreover, whilst Yaxely and Zwaan's 2005 study still had the issue of emotion and a lack of

experimental controls in their task, the present thesis used a non-emotional and arbitrary stimulus – the colour green – with stringently controlled bottom-up stimulus information. Differential behaviour in trials that included a green object was taken as evidence of an induced attentional bias in the absence of emotion; this was precisely what was observed. Perceptual sensitivity in trials where green items changed was significantly increased by the single information sheet, and presence of a green stimulus in trials where an alternative stimuli changed colour resulted in reduced perceptual sensitivity (Chapters 2 and 3).

Although these effects relate to normative populations with arbitrary stimuli, they mirror the effects observed in abnormal populations with maladaptive biases. Investigations of maladaptive biases all show consistent findings of task-relevant bias-related information speeding performance (Jones et al., 2006; Jones et al., 2003) and task-irrelevant bias-related information disrupting behaviour (Cox et al., 2000; Johnsen, Laberg, Cox, Vaksdal, & Hugdahl, 1994a). Using the one-shot change detection paradigm, when changes occurred to biased stimuli (green probes changed colour), performance was improved suggesting attention was allocated towards these items. On the other hand, when changes occurred to alternative stimuli but biased stimuli were also present (a different coloured probe changed colour but a green item was also present), performance worsened, suggesting the irrelevant green item disrupted behaviour.

Furthermore, maladaptive biases are known to be highly robust, and it is difficult to interfere with them (Field et al., 2007; Schoenmakers et al., 2007). Throughout this thesis, the induced bias still affected behaviour at least two weeks after the information sheet was first read (Chapters 1, 4 and 5; especially Chapter 2), and an initial induced bias to green items still persisted when a second attentional bias was induced (Chapter 5). A key aspect of maladaptive biases lies in an individual's inability to overcome the bias (Field & Cox, 2008), thus this thesis imitates this aspect of maladaptive biases, showing that a single information sheet induces persistent and highly robust attentional biases that are difficult to interfere with. It existed with and without an added motivation to attend

to green objects (Chapters 2 and 3), and had a negative impact on behaviour when bias-related items were both explicitly and implicitly task irrelevant – again, up to a full two-weeks after the initial information sheet was read (Chapters 3 – 5). These results reflect previous findings of maladaptive attentional biases, strongly suggesting that the experiments within this thesis were successful in inducing an attentional bias towards an arbitrary stimulus in a normative sample, thus probing the cognitive aspects of attentional bias.

The orienting of visual attention is dependent on the impact of both bottom-up (the physical saliency of items) and top-down (not related to stimulus saliency) information. This information feeds into a priority map, which determines how attentional recourses are allocated (Awh et al., 2012; Fecteau & Munoz, 2006; Theeuwes, Olivers, & Chizk, 2005). Ordinarily, bottom-up information carries a greater amount of weight on the priority map (Itti & Koch, 2000; Kawahara, 2010). However, with attentional bias, the contributed impact seems to be altered in that top-down information now carries more weight (Bacon & Egeth, 1994; Folk & Remington, 1998; Folk et al., 1992; Leber & Egeth, 2006b). While the qualia of colours (how 'red' appears to one person compared to another) cannot be controlled, all experimental stimuli used throughout this thesis were of equal size, luminance, and visual angle, and their positions were randomised on each trial. If bottom-up information was the main contributor to the priority map, accuracy, speed and perceptual sensitivity would be equal in all conditions. The fact that a single information sheet caused differing behaviours towards green items suggests that this information sheet has skewed the contributions to the priority map, giving more weight to top-down information relating to green and increasing perceptual sensitivity of these items.

This provides an important contribution to the study of visual attention. There has been a longstanding debate within cognitive psychology over the past two decades regarding the nature by how visual information is selected for further processing. One argument is that information is initially selected based purely on its physical bottom-up attributes (brightness, contrast), with the

most physically salient item always awarded priority (Belopolsky & Theeuwes, 2010; Koch & Ullman, 1985; Theeuwes, 1991, 1992, 1994, 2004, 2010a; Theeuwes & Godijn, 2002; Theeuwes et al., 2004). Only when this initial sweep of bottom-up information has occurred can top-down cognition influence selection – though the extent to which this sweep occurs depends on the dimensions of a so-called "attentional window", whose size is controlled in a top-down manner (Belopolsky & Theeuwes, 2010). This theory argues against any top-down contribution on the initial capture of visual attention. However, the findings throughout this thesis provide substantial evidence that this is not the case. A single information sheet caused related stimuli to affect early attentional processing (perceptual sensitivity), in a task where participants had only the one chance to detect a change or not – suggesting the task was able to probe early attentional capture. A neutral information sheet resulted in no difference in perceptual sensitivity, demonstrating that the information sheet was affecting early attentional capture in a top-down manner.

The alternative theory to Theeuwes' emphasis on bottom-up driven attentional capture states that early attentional orienting can be modulated based upon a top-down established attentional setting (Becker et al., 2013; Folk et al., 1992; Irons, Folk, & Remington, 2012). Here, items congruent to the attentional setting – in the case of this thesis, green items – are awarded priority and go on to capture attention. It is likely that this priority is due to a bias of neural competition that raises the excitability of neurons relating to items congruent to the attentional set (Desimone & Duncan, 1995). This model suggests that those with an attentional bias have a persistent attentional setting favouring bias-related information, meaning that this information goes on to capture and hold visual attention even when more physically salient information is available. The findings throughout this thesis support this model, implying that the information sheets caused the implementation of an attentional setting favouring green items. What is interesting to note is that this attentional setting was not only very straightforward and effortless to establish – requiring only a single reading of the information sheet – but also long-term, in that it was still present two weeks after it was formed.

The mechanism behind the attentional set speaks to a series of studies investigating various search modes that can be selected to aid in the navigation of the visual world (Bacon & Egeth, 1994; Leber & Egeth, 2006a, 2006b). As outlined in the general introduction, Bacon and Egeth (1994) propose the existence of two different modes of search; Singleton Detection and Feature Search Mode. Singleton Detection Mode is based purely on bottom-up salience with the most salient item capturing attention. It also appears to be the default search mode (Kawahara, 2010). Feature Search Mode on the other hand relies on a defining target feature that results in a reduction of interference from salient objects incongruent with this feature. Arguably, search mode selection is under top-down control, and depends on which mode offers optimum performance in any given situation. Searching for a particular item – such as a café at lunchtime – will activate a Feature Search Mode favouring items relating to food. Crossing a busy street on the other hand will activate Singleton Detection Mode, so that the sudden appearance of a fast car will automatically capture attention.

Although not tested directly, it appears as if a persistent alteration to a Feature Search Mode may be the mechanism by which the alteration to the attentional setting is made. Evidence for the use of Feature Search Mode is observed in tasks where items are selected for reasons other than their bottom-up salience (Kawahara, 2010; Leber & Egeth, 2006a, 2006b; Leber et al., 2009). In Chapters 2 and 3, green items were preferentially attended to, despite all stimuli being equal in terms of physical saliency. This preferential selection of green information was still displayed in subsequent testing sessions (up to two weeks later), demonstrating that green items were selected for a reason not relating to their saliency. These results therefore suggest that the information sheet caused a persistent alteration to Feature Search Mode by participants throughout this thesis. What is interesting is that findings across all chapters suggest a stimulus-specific long-term alteration of Feature Search Mode has occurred, rather than a preference for Feature Search Mode in general (Leber & Egeth, 2006a). Previous experiments implicitly and procedurally trained subjects and then placed them in ambiguous settings wherein either search mode could be effectively used (Kawahara, 2010; Leber & Egeth, 2006a, 2006b; Leber et al., 2009). These studies firstly showed that long-term

alterations favouring a particular attentional setting must be learned over a sufficiently long training phase (Leber & Egeth, 2006), but also that they reflect a more abstract learning of choice of mode – Singleton Detection or Feature Search (Leber et al., 2009) – rather than a stimulus-specific version of each, with Singleton Detection Mode adopted in the absence of training (Kawahara, 2010).

The experiments in this thesis however, have found that a long-term stimulus-specific selection of a search mode is possible, and easy to induce. These findings mean that attentional biases can develop very easily, with minimal effort and no need for emotion or motivation. It should be noted that since it is behaviourally relevant (and behaviourally advantageous) to attend to green items in the colour change-detection tasks in each chapter, this could be construed as a "training phase" to attend to green items. Nevertheless, it is a much shorter training phase than those used in previous studies (Leber & Egeth, 2006a), and should also not persist when it is behaviourally disadvantageous, as it is in the shape tasks. Moreover, the fact that is persists when a second competing attentional setting is activated (Chapter 5) speaks to the strength of the initial altered settings. It is possible that the disparity between the findings in this thesis and these previous training studies are due to methodological differences. The current thesis used an explicit information sheet inducing a long-term stimulus-specific search mode. However, previous studies such as Leber et al. (2009) used sequential training with online feedback to implicitly train participants to activate Feature Search or Singleton Detection mode. Had Leber and colleagues used sequential training alongside a more explicit cue – such as the name of a colour in task instructions – a long-term, stimulus-specific Feature Search Mode may have developed. Nevertheless, this does not detract from the findings of this thesis which build upon the existing literature, advancing our understanding of top-down mechanisms of visual attention.

The present results therefore also reflect those observed in the maladaptive attentional bias literature. Here, patients are unable to favour attentional control settings towards items not related to their pathology (Schoenmakers et al., 2007). This is especially demonstrated in Chapter 5, wherein

participants were unable to remove their attentional control settings towards green items after being informed that they should now be favouring blue items. Instead of a second bias eliminating the first, the attentional bias towards green objects was present in addition to the attentional bias towards blue objects. This sustainable bias towards green displays the inability of participants to overcome the initial induced bias. Also, the behavioural effects when both green and blue objects were present shows not only that biases are difficult to amend, but that in combination attentional biases cause additive effects – distracting participants away from behaviourally relevant information even more than when presented in isolation. Behaviour of participants in this thesis therefore appears to mirror behaviours observed by various populations with maladaptive attentional biases. This offers further support that a persistent alteration to Feature Search Mode is analogous to a persistent attentional bias, and also supports the argument that the information sheets used in all experimental chapters were successful in inducing an attentional bias towards a non-emotional and arbitrary stimulus which affected early visual sensitivity and responder bias (and which in turn, affects both accuracy and reaction times).

The inducement of a non-emotional bias also has major ramifications for abnormal and pathological theories of the development of attentional biases. It is repeatedly demonstrated throughout this thesis that there is no prerequisite for repeated exposure to cues and responses for an attentional bias to form. Thus, there is no need for gradual exposure to a drug resulting in altered responses in the mesolimbic dopamine system raising the salience of bias-related items (Berridge, 2007; Berridge & Robinson, 2003; Franken, 2003; Kelley & Berridge, 2002; Koob, 1992; Melis, Spiga, & Diana, 2005; Robinson & Berridge, 1993, 2008; Weiss, 2005; Wiers et al., 2007). This has not been observed in previous studies (Robinson & Berridge, 1993; Tiffany, 1990). Finally, there is no requirement of an emotional attachment towards a particular stimulus or category of stimuli for a bias to form. This is particularly relevant to theories in anxiety, which suggest that hyper-vigilance for threat to monitor for potential dangers (Armstrong & Olatunji, 2012; Richards et al., 2014) is an underlying cause of threat-related items capturing attention. The development of this hyper-vigilance is believed to stem

from conditioning (Dawson et al., 1982; Van Damme et al., 2006; Van Damme et al., 2004) and the internal need to avoid conditioned responses from conditioned stimuli. Instead, it is repeatedly demonstrated that a single information sheet is sufficient to alter attentional control settings and induce a robust attentional bias that persists outside an immediate testing paradigm.

These findings suggest that the posited alterations to Feature Search Mode may be a central underpinning of attentional bias across all populations that display one, and thus, may be the cognitive aspect of the phenomenon that transcends pathology. This would mean that in abnormal populations, altered attentional control settings occur first, and are then reinforced by the population-specific aspects. In addiction-related attentional biases for example, attentional control settings would therefore be initially altered towards drug-related stimuli, but are then reinforced by reward, which most likely recruits additional neuronal processing involving the mesocorticolimbic dopamine system (Baler & Volkow, 2006; Berridge, 2007; Franken et al., 2005; Goldstein, Tomasi, et al., 2009). Support for this is evident in Chapter 4, where otherwise healthy heavy social drinkers who drink significantly more alcohol than light social drinkers but who are not addicted, already have attentional control settings favouring alcohol-related items. This shows that in the absence of alcohol consumption becoming a problem (thus in the absence of cravings and urges that encompass alcohol addiction but not social alcohol consumption), an object-specific alteration to an attentional control setting can still occur and be used as a strategy for scanning a scene. It should also be noted that in this group, the information sheet was still able to cause an alteration to these attentional control settings to favour green items, however this strategy was only utilised when green items were behaviourally relevant. When task-irrelevant, the green objects did not cause as much of a distraction as they did for light social drinkers who had no feature-specific attentional control setting currently active.

The consistent findings throughout this thesis appear even more robust when considering the populations tested. Since there is no previous overlap between the pathological bias literature and

the cognitive attention literature, there is a lack of consistent controls placed on populations used to traditionally investigate attentional bias. Thus, findings relating to the development of attentional bias that *do* place constraints on participant populations appear to provide sounder explanations of these behaviours, since the behaviour can be attributed to the bias and not to an underlying pathology. However, the terminology of 'attentional bias' is not used in cognitive studies that examine the effects of top-down control settings on the orienting of attention, which is arguably the cognitive mechanism underlying attentional bias. This issue potentially contributes to the lack of communication between these the cognitive literature on visual attention and the abnormal literature on maladaptive biases. The experiments within this thesis have helped to bridge this gap, by examining attentional bias from a cognitive perspective, while using background evidence both from the cognitive and abnormal lexicons alongside a more tightly controlled pool of participants throughout: undergraduate students all selected from the same university population.

This use of comparable participants has therefore enabled the investigation of attentional bias free from potential confounds. Previous studies examining addicted populations and comparing findings to healthy groups incur confounds relating both to the physical differences in brain structures (Chanraud et al., 2007; Harper, 1998, 2009; Harper, Dixon, Sheedy, & Garrick, 2003; Harper & Matsumoto, 2005; Medina et al., 2008; Oscar-Berman & Marinkovic, 2007; Pfefferbaum, Sullivan, Mathalon, & Lim, 1997) and differences in neurotransmitter functioning (Addolorato, Leggio, Hopf, Diana, & Bonci, 2012; Colombo et al., 2004; Dodd, Beckmann, Davidson, & Wilce, 2000; Gass & Olive, 2008; Samson & Harris, 1992; Walker & Koob, 2007). With clinical depression, these involve atypical structure and resulting functioning of brain regions including the PFC, amygdala and hippocampus (Baxter Jr et al., 1989; Cotter et al., 2002; Hastings, Parsey, Oquendo, Arango, & Mann, 2004). Similarly in those suffering from anxiety physical differences in prefrontal regions compared to healthy controls exist (Almeida et al., 2009; Bishop et al., 2004; Davidson, Marshall, Tomarken, & Henriques, 2000; Davidson, Putnam, & Larson, 2000; Ducharme et al., 2013; Mathew et al., 2004).

These atypical brain structures and functioning raise serious concerns with traditional investigations of attentional bias, since it is unknown to what – if any – extent the neurological differences have on participant behaviour. Of particular concern are the differences in prefrontal structure and functioning, since the PFC is implicated both in cognitive control (Fassbender et al., 2004; Miller, 2000; Miller & Cohen, 2001; Spreng et al., 2013) and in the establishment of attentional control settings (Banich et al., 2000; Luks et al., 2007; Luks et al., 2002). Consequently, there is no way of knowing if these reductions in prefrontal activity contribute to the initial alteration of attentional control settings (initial establishment of the attentional bias), or the control of incoming visual information (the extent to which bias-related objects capture and hold attention). Given the multiple roles of the PFC, the ramifications of these differences in previous experimental populations could be large. The use of healthy, comparable participants in this thesis overcomes these issues. Furthermore in Chapter 5, no differences in executive functioning between any groups of participants – including between heavy and light social drinkers – was found. This demonstrates that the findings from thesis allow for a direct comparison between both the sub-clinical subgroups used, and with populations from the general cognitive literature.

This thesis has also allowed for a neurological exploration of the precise role of the PFC in attentional bias. Given that this region plays a crucial role in cognitive control and executive functioning (Cabeza & Nyberg, 2000; Groman et al., 2009; Koechlin et al., 2003; Rossi et al., 2009), it is almost no surprise that atypical PFC activity is so commonly observed in populations who have well documented attentional biases (Bishop et al., 2004; Hester & Garavan, 2009). Since the PFC is involved in cognitive control, it logically follows that those with reduced PFC functioning would be more susceptible to distractions caused by attentional biases as they are less able to exert control over irrelevant bias-related objects in order to maintain attention towards task-relevant objects (Kane & Engle, 2002; Ryan, 2002). As discussed, it was previously unknown if atypically functioning PFCs were the mediating factors in traditional studies of attentional bias or if the inconsistent findings were a consequence of the methodological limitations already discussed.

The studies conducted throughout this thesis help to elucidate this discrepancy. Findings from all chapters suggest that those in higher education with high PFC functioning to meet these demands (Ostlund & Balleine, 2005; Prabhakaran et al., 2000; Ramnani & Owen, 2004; Winocur & Moscovitch, 1990) can display persistent and pre-existing attentional biases. Furthermore, Chapters 3-6 show that these biases are observed when bias-related items are behaviourally-irrelevant and thus distract attention away from task-relevant information. Therefore, while reduced PFC functioning may aid in the establishment of a bias, reduced PFC function is not a prerequisite for this formation, since this thesis demonstrated attentional bias developing in high PFC functioning individuals. Additional findings also suggest that having a pre-existing attentional bias can affect how future developing attentional biases are dealt with. Chapters 4 and 5 both show that heavy social drinkers from the same cohort as light social drinkers (none of whom also smoked or took recreational or prescribed drugs) act differently when an additional attentional bias (in the case of the heavy social drinkers) is induced. When one arbitrary attentional bias is induced (Chapter 4), light social drinkers were more distracted by the bias when it was explicitly task-irrelevant. When two arbitrary biases are induced (Chapter 5), there is no difference in the perceptual sensitivity (how distracted participants were by bias-related items) in heavy versus light social drinkers. However only heavy social drinkers become more restrained and conservative with their responses (their internal criterion of the point at which changes or no-changes is reported).

These findings can be explained in one of two ways. Firstly, it is possible that the attention network that prioritises certain information over others is already in use in heavy social drinkers (for their pre-existing alcohol-related attentional biases). Since this network is not currently in use for light social drinkers, it is activated following the initial bias-inducing information sheet. This results in light social drinkers becoming more distracted by green items than heavy social drinkers. In terms of attentional control settings, this explanation suggests that a persistently engaged stimulus-specific Feature Search Mode (heavy social drinkers for alcohol-related items), it is difficult to subsequently interfere with or alter. When there are no persistent alterations in place (light social drinkers),

attentional control settings can be easily activated and go on to cause long-term effects on attentional deployment. However, during the initial colour change experiment, the sensitivity of heavy compared to light social drinkers was indistinguishable. It was only in the shape task – after being explicitly advised that colour was now irrelevant – that the differences in perceptual sensitivity were observed. This suggests no difference in the ease of inducing an attentional bias in heavy and light social drinkers, but on how well biases can be controlled for after they develop.

Due to this, an alternative explanation is proposed. When those with high executive functioning and highly exercised PFCs who already hold a pre-existing attentional bias have additional attentional biases induced, they already have a set of cognitive control mechanisms in place to deal with potential distractions caused by their pre-existing attentional settings. These cognitive control mechanisms can then be recruited to minimise distractions caused by subsequently induced biases. When no pre-existing bias exists, the control mechanisms to manage distractions do not exist. Thus, when attentional settings become persistently altered there are no pre-existing tools to available control for distractions, reducing perceptual sensitivity when bias-related information is explicitly irrelevant – a pattern clearly displayed by light social drinkers in Chapters 4 and 5. However, findings in Chapter 5 place a limitation on this, since even those with high executive functioning who have experience controlling for one bias cannot fully control for distractions caused by two. It is therefore possible that high executive functioning otherwise healthy adults who hold two pre-existing biases may display greater control over distractions caused by two irrelevant induced biases. However, it must be noted that despite using strict inclusion/exclusion criteria, there may have been participants who did hold multiple pre-existing attentional biases (i.e., towards food or health-related issues etc.). While every attempt was made to ensure the selection of participants was as controlled as possible, it may be methodologically impossible to test an absolutely clean sample of participants who unequivocally hold only one pre-existing attentional bias due to the seemingly endless amount of stimuli that people can hold an attentional bias towards.

Despite this, these combined findings strongly suggest that individual differences in PFC and executive functionality alter the way in which attentional biases manifest and their impact on behaviour. The development of additional biases in individuals with high executive functioning interacts with the ability to develop controlling mechanisms that prevent attentional-bias related items from impacting upon behaviour when they are known to be irrelevant to current behavioural goals. One way to explicitly test for this could be to test heavy and light social drinkers with low executive functioning, in order to establish if the heavy social drinkers firstly have control mechanisms in place to control for their alcohol-related attentional biases, and if so, to examine whether these can be recruited to control for distractions caused by further induced attentional biases.

An alternative to probe the critical role of the PFC in attentional bias is to utilise neurostimulatory techniques (Chapter 6). Using tDCS, this thesis discovered further compelling evidence of a critical role of the PFC (specifically the left DLPFC) in both the establishment of a stimulus-specific Feature Search Mode, and on the cognitive control of irrelevant items congruent with this attentional setting (Banich et al., 2000; Garavan et al., 2002; Luks et al., 2007; Luks et al., 2002). Cathodal tDCS which decreases excitability of underlying neurons (Nitsche et al., 2009; Nitsche et al., 2008; Nitsche & Paulus, 2000, 2001) negated the biasing effects of the initial information sheet, causing participants to behave as if they had no attentional bias present to begin with. On the other hand, anodal tDCS which raises the excitability of the underlying neurons (Nitsche et al., 2009; Nitsche et al., 2008; Nitsche & Paulus, 2000, 2001) increased the cognitive control over irrelevant, bias-related distractors, supporting previous literature of a role of the left DLPFC in cognitive control (Bishop et al., 2004; Bishop, 2009; Bishop et al., 2007; Hester & Garavan, 2009; Kerestes et al., 2012).

These findings help in advancing our understanding of the critical role of the PFC in attentional bias in multiple ways. Firstly, using the one-shot change detection paradigm ensured an appropriate methodology for testing. Secondly, this study used the same highly educated cohort which helped to

clarify previous research using anodal tDCS over the left DLPFC in a group of patients with major depressive disorder (Wolkenstein & Plewnia, 2013). While both the findings from the current thesis and those in Wolkenstein and Plewnia (2013) provide corroborating results demonstrating that increasing the excitability of the left DLPFC improves cognitive control, participants in Wolkenstein and Plewnia not only suffered from a psychiatric condition but were receiving neurologically-altering medication to treat this condition (Carr & Lucki, 2011; Millan, 2004; Musazzi et al., 2011; Skolnick, 1999; Willner, 1985) – potentially altering the effects of the tDCS. However, it should be noted that participants in this thesis were not at ceiling in controlling for induced attentional biases (not light or heavy social drinkers, nor participants in the tDCS experiment). This may be related to the age at which the PFC is fully matured. Full maturation of the PFC in terms of decreasing grey matter and increasing myelination (Paus, 2005) is around 23 years of age (Gogtay et al., 2004). In this thesis, the majority of participants were aged between 18 and 22 and thus would have differed in the extent to which their PFCs were fully matured. A further investigation of the precise role of the PFC in the development and control of attentional bias could therefore use a sample of participants with high functioning and fully matured PFCs (aged 30-40 years; Paus, 2005), to examine the extent to which the PFC is able to exert control, and the ease of disrupting this control following full myelination.

Taken together, the findings from Chapters 4-6 show that the left DLPFC plays a pivotal role in attentional bias. Firstly, it is involved in creating the attentional control settings that feed forward to the attention network (Banich, 2009; Banich et al., 2000; Silton et al., 2010) allowing for the prioritisation of certain stimuli. Neurons that code for aspects of these stimuli are then biased to respond (Desimone & Duncan, 1995; Kastner et al., 1999; Kastner & Ungerleider, 2000; Serences & Yantis, 2006). As a result, related stimuli are preferentially represented on the priority map (Awh et al., 2012; Fecteau & Munoz, 2006) resulting in overt shifts of attention (Greenberg, Esterman, Wilson, Serences, & Yantis, 2010; Serences & Yantis, 2006). The left DLPFC then exerts control over this process, suggesting that it not only feeds information forward to the dorsal frontal-parietal attention network (Corbetta et al., 2002; Corbetta & Shulman, 2002; Reynolds & Chelazzi, 2004), but

also receives information back before relaying an updated atlas of what to continue to attend to and what to ignore (Benchenane, Tiesinga, & Battaglia, 2011). This ensures that visual attentional is not unnecessarily captured or utilised by irrelevant objects (Corbetta & Shulman, 2002; MacDonald et al., 2000). Consequently, the PFC is able to exert more high-level cognitive control, potentially by adjusting the peaks on the priority map in favour of task-relevant information over distractions caused by irrelevant attentional-bias related information (Fecteau & Munoz, 2006; Ptak, 2012).

One suggestion of future research could be to use a more conservative technique that allows for a closer examination of the timings of neural processing. Such an option would be Transcranial Magnetic Stimulation (TMS), which disrupts normal neural functioning at very specific timings (Walsh & Cowey, 2000). Using this technique would therefore enable the investigation of the importance of the left DLPFC in the initial formation of attentional control settings versus its role in cognitive control of attention and distractions caused by these settings. If disrupting the involvement of the left DLPFC early in a task when the control settings are being formed causes a decrease in distractibility, this would suggest that the formation of attentional control settings are critical in first establishing an attentional bias. Alternatively, if disrupting left DLPFC involvement during a task including irrelevant bias-related causes an increase in distractibility, this would suggest that the cognitive control of the environment is of paramount importance. While the former would provide strong evidence of the neural basis of attentional control settings, it seems likely that in those with an already established attentional bias that the latter investigation would prove more fruitful. The use of the one-shot change detection task would also be highly beneficial. A reduction or increase in perceptual sensitivity following TMS interference at different stages (during the display of the first visual array, the mask, or the reappearance of the array) would provide further information on the temporal aspects of neural activation when participants are presented with bias-related items.

Nevertheless, despite the evidence of a causal role of the left DLPFC in the development and control of attentional bias, there is a future study that the results from Chapter 6 warrant; a closer investigation of the role played by the OFC. In Chapter 6, it was discussed that while the primary aim of the neurostimulation study was to obtain causative data on the left DLPFC, the reference electrode used was situated over the right eye. This would have stimulated the right OFC, and may have contributed to the experimental findings. The OFC is implicated in decision making, in that it receives a variety of sensory and cognitive information, and forms a goal-value based upon this information (Bolla et al., 2003; Camus et al., 2009; Rolls, 1999, 2000; Rolls & Grabenhorst, 2008; Volkow & Fowler, 2000; Wallis, 2007). Disrupting the OFC may have therefore had an effect on either the ability to form the goal-value, or the ability to receive sufficient information to form the goal-value. In the task, participants were asked to decide on whether a change was present between two arrays or not after reading the bias-inducing information sheet. Disputing this area may have influenced the cognitive input it was able to receive, or disrupted the ability to form a decision based upon this information, potentially affecting results. Future studies should therefore look to investigate the differences between left DLPFC stimulation and right OFC stimulation following the inducement of an arbitrary attentional bias to clarify the involvement of these areas – separately or in combination – in the development and control of attentional bias. Alternatively, investigations of the co-involvement of the PFC and OFC could use tDCS and fMRI concurrently. Thus could elucidate the dual involvement and interconnectivity between the left DLPFC and right OFC, by examining firstly the effects of placing the reference electrode above the right eye, and also examining if left DLPFC stimulation also affects OFC activity. Likewise, this could also probe other areas connected with the left DLPFC that also play a role in the establishment of attentional settings and the cognitive control of information relating to these settings.

The findings throughout this thesis have direct ramifications for a re-evaluation of the abnormal literature relating to attentional bias, its aetiology and its role in psychopathological issues and how it may be manipulated in treatment paradigms. Attentional bias has been typically investigated

within the abnormal literature (Gotlib et al., 2004; Mogg & Bradley, 2005; Moritz, Von Muhlenen, Randjbar, Fricke, & Jelinek, 2009; Shin, Hopfinger, Lust, Henry, & Bartholow, 2010; Smeets, Roefs, van Furth, & Jansen, 2008; Tata, Leibowitz, Prunty, Cameron, & Pickering, 1996), yet these findings are clouded with pathology-specific aspects of these studies. This thesis has investigated attentional bias from a cognitive perspective, with findings suggestive of a cognitive underpinning of attentional bias – a persistent selection of a stimulus-specific form of the attentional setting Feature Search Mode. The finding that there is a probable cognitive mechanism common to all exhibited forms of attentional bias also suggests a potential avenue for neurorehabilitation in these psychopathologies. Enabling sufferers to exert more control over their environment will reduce distractions caused by their attentional biases which in turn could prevent cravings and relapse (Field & Cox, 2008; Field & Eastwood, 2005; Field, Munafo, et al., 2009). Such combinations of behavioural and neurostimulatory interventions have been shown to improve behavioural inhibition (Ditye, Jacobson, Walsh, & Lavidor, 2012). Thus, cognitive training to better control for the distractions caused by irrelevant bias-related information alongside neurostimulation could be utilised as a potential route for treatment.

Importantly, this potential neural rehabilitation is not pathology-specific, since the experiments within this thesis show a general cognitive basis of attentional bias, along with a neural region that can help to control for this cognitive basis. This potential is highlighted in Wolkenstein and Plewnia's (2013) study, showing a beneficial effect of anodal tDCS over the left DLPFC in chronically depressed patients, however this thesis has shown evidence of a beneficial effect of both anodal and cathodal left DLPFC in healthy participants controlling for arbitrary distractions. Replicating these findings within other clinical populations would support the findings from this thesis even further still. Hence, the findings throughout this thesis have far-reaching implications, are socially sensitive and may have a real impact upon many areas in abnormal psychology and wider healthcare in general.

In summary, this thesis has succeeded in the primary aim to investigate attentional bias from a cognitive standpoint. The findings from this investigation have then been used to gather insight on abnormal populations that display biased attention by looking at a pre-clinical sample. Typically studied within the abnormal literature, but with a clear cognitive basis that was hitherto not appropriately studied, this thesis has demonstrated a common central cognitive aspect of attentional bias exists in that attentional biases form as a result of specific and chronic alterations in the feature search attentional setting. A key neural substrate of these formations is the left dorsolateral prefrontal cortex, which is also involved in exerting control over the settings when items relating to the bias are present, but behaviourally irrelevant. Targeting this region in an attempt to enhance this cognitive control may provide an avenue for the neurorehabilitation of a vast array of psychopathologies, bringing the findings of this thesis relating to attentional bias to bear on their traditional abnormal roots.

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Appendix A

Neutral Information Sheet

Colour Perception

Participant Information Sheet

Thank you for taking the time to visit the lab. I'm hoping that you will agree to take part in an experiment.

The experiment requires you to be seated in front of the computer screen with your head in the chin rest. You will see a fixation cross on the screen which you should remain fixated on. This will disappear and be replaced by a circular array consisting of 6 different coloured circles. The array will then appear to 'flicker'. Following the flicker, one of the circles *may* or *may not* have changed colour. A change will not be present in all trials, and can be to any of the 6 colours, in any of the locations. Your task is to indicate via the button box if you saw a change or not.

- If you DID see a change, click the LEFT button
- If you DID NOT see a change, click the RIGHT button.

You will have 2800ms to respond. Please answer as QUICKLY and as ACCURATELY as possible.

If you agree to take part in this study could you please fill in an Informed Consent form.

The details on this form will be stored in a different place to the results from the study, and should the study ever be published, your results will not be identifiable. They will remain completely anonymous.

Your taking part in this general survey is entirely voluntary and you may decline to take part now or decline to continue taking part at any point of the proceedings.

Thank you for considering this request.

Appendix B

Biasing Information Sheet

Perception of the Colour Green

Participant Information Sheet

Thank you for taking the time to visit the lab. I'm hoping that you will agree to take part in an experiment investigating how humans perceive the colour Green.

The experiment requires you to be seated in front of the computer screen with your head in the chin rest. You will see a fixation cross on the screen which you should remain fixated on. This will disappear and be replaced by a circular array consisting of 6 different coloured circles. There will be a Green circle present in many trials. The array will then appear to 'flicker'. Following the flicker, one of the circles *may* or *may not* have changed colour. A change will not be present in all trials, and can be to any of the 6 colours, including Green, in any of the locations. Your task is to indicate via the button box if you saw a change or not.

- If you DID see a change, click the LEFT button
- If you DID NOT see a change, click the RIGHT button.

You will have 2800ms to respond. Please answer as QUICKLY and as ACCURATELY as possible.

If you agree to take part in this study investigating the colour Green could you please fill in an Informed Consent form.

The details on this form will be stored in a different place to the results from the study, and should the study ever be published, your results will not be identifiable. They will remain completely anonymous.

Your taking part in this general survey is entirely voluntary and you may decline to take part now or decline to continue taking part at any point of the proceedings.

Thank you for considering this request.

Appendix C

Shape Information Sheet

Change Detection

Participant Information Sheet

Thank you for taking the time to visit the lab. I'm hoping that you will agree to take part in an experiment.

The experiment requires you to be seated in front of the computer screen with your head in the chin rest. You will see a fixation cross on the screen which you should remain fixated on. This will disappear and be replaced by an array consisting of 4 different coloured shapes. The array will then quickly disappear then reappear, seeming to 'flicker'. Following the flicker, one of the shapes *may* or *may not* have changed shape. The colour of the shape will always stay the same. **As such, attending to a particular colour will be disadvantageous**. A change will not be present in all trials, and can be to any of the 4 shapes, in any of the locations. Your task is to indicate via the button box if you saw a change or not.

- If you DID see a change, click the LEFT button
- If you DID NOT see a change, click the RIGHT button.

Please answer as QUICKLY and as ACCURATELY as possible.

If you agree to take part in this study could you please fill in an Informed Consent form.

The details on this form will be stored in a different place to the results from the study, and should the study ever be published, your results will not be identifiable. They will remain completely anonymous.

Your taking part in this experiment is entirely voluntary and you may decline to take part now or decline to continue taking part at any point of the proceedings.

Thank you for considering this request.