The interplay between attention, working memory, and linked neural signatures in visual tracking and inhibition

The Interplay between Attention, Working Memory, and linked Neural Signatures in Visual Tracking and Inhibition

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Declaration

I certify that the work presented in this thesis is my own original work and is for examination for the Doctor of Philosophy in Psychology degree.

Signature:

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Abstract

The aims of this thesis began with investigating whether inattentional blindness was associated with a propensity for lower sensitivity to semantic violations in image textures. Inattentional blindness has recently been investigated through methods such as manipulation of low-level image statistics in artificial textures. However, work in this thesis aimed to transition such research into more natural contexts. Whilst a variety of methods were explored, results specifically related to inattentional blindness and working memory capacity remained inconclusive. Therefore, work in this thesis moved from investigating differences across inattentional blindness groups to how potential strategies of object tracking and relationships to working memory capacity can influence tracking performance. Results from the first half of this thesis provide novel insights into methods that can help to investigate sensitivity to distractors in a naturalistic setting, with both behavioural and neural data.

This shift away from investigating inattentional blindness to patterns of tracking across working memory capacity also coincided with a shift to linear mixed effects modelling. This allowed the thesis to remove any artificial grouping through median scores of capacities, and instead focus more on sensitivity across the spectrum. Over five tracking studies, a number of findings suggest of differences across working memory capacity can compensate in performance for such capacity limitations. Findings also suggest that participants, regardless of capacity, employ a post-probe approximation estimation when tracking targets over a trial gap, as opposed to active tracking. Results from the tracking studies emphasise the differing approaches that individuals with varying working memory employ when tracking multiple and single objects.

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Thank you.

Table of Contents

List of Figures

List of Tables

Chapter 1. Introduction

1.1 Overview of Chapter

The following chapter begins with the overarching aims and rationale of the thesis. It will also provide a justification for changing the focus of the research from inattentional blindness and associated links to processing of distractors, to patterns in object tracking across working memory capacity. The chapter will introduce the inattentional blindness phenomenon, providing the theoretical background and current research. The section will then present evidence for the link between working memory capacity and inattentional propensity, which was the association tested in the first empirical chapter of the thesis and continued to carry links in the remaining chapters. The chapter will then introduce literature on object tracking and consequent links to related mechanisms in object tracking and screening for inattentional blindness. This section will then incorporate links to the multiple object tracking paradigm, as it was used in the last empirical chapter of the thesis. The very last section of this chapter will provide a brief overview of the following chapters to come.

1.2 Thesis Aims and Rationale

The initial aims of this thesis were to investigate differences in sensitivity to saliency in real-world images, and whether such differences are predicted by levels of inattention. However, the results of this early research influenced the direction of the thesis, as detailed in the later sections. Work began to extend findings of differences in saliency across inattentional blindness to artificially produced images to images that carried more real-World semanticity. Novel application of image manipulation techniques was used to assess whether such effects could be replicated, in line with research that has been conducted with simple visual stimuli, and the resource-based hypothesis of inattentional blindness. However, given the limitations of methods used in categorising inattentional blindness, work in this thesis then diverged to investigate whether tracking performance and strategy differs as a function of working memory capacity. The rationale for this change was based on findings from existing research, which states that working memory capacity resources predicts the level of inattention, and from limitations outlined in this thesis, where tracking strategy may influence performance on tasks that categorise inattentional blindness.

The analysis strategy also evolved as research was conducted, specifically in two forms: firstly, methods ranged from behavioural measures to measures of electrical brain activity. Behavioural methods served to not only isolate differences in accuracy to tasks, but also to tracking patterns, validated categorisation for stimuli, and comparison of behavioural rates to neural patterns. Similarly, electroencephalography (EEG) was used in order to assess whether individuals display the same neural strategy to reach a behavioural outcome. For this aim, event related potentials (ERPs) were used, as they carry millisecond resolution to experimental manipulations – exact components are discussed in the chapters where they are used. The second way in which the analysis changed was from an emphasis on group methods to a more encompassing view on individual differences. As while categorisation of inattentional blindness is binary, working memory capacity is measured on a spectrum.

The aims of the thesis also carry a number of ramifications outside of research, firstly, inattentional propensity carries a number of implications for vigilance type job roles, such as noticing weapons in routine police stops (Simons & Schlosser, 2017), and everyday tasks, such as driving, where the ability to notice emerging dangerous situations is vital. Therefore, finding predictors of such behaviours that increase danger in such situations can help to create training programmes or frameworks that can ultimately reduce harm to individuals and society. Furthermore, work that centres around working memory capacity carries more everyday implications. Work in this thesis aims to investigate whether lower working memory capacity individuals diverge in their approach to tracking. Differences in approach to tasks, that are dependent on working memory capacity, therefore carry implications for bespoke educational and professional training frameworks, that allow more flexibility for individuals to achieve the same behavioural outcome as others. The following section will now introduce inattentional blindness and provide the rationale behind investigating the ability to predict inattention from working memory capacity.

1.3 Inattentional Blindness and Working Memory Capacity

The following section will introduce inattentional blindness literature, beginning with a brief introduction and definition, before also introducing background theory for working memory capacity. Both concepts are essential to the work completed in this thesis and are therefore discussed in some depth. The last subsection will discuss the links between both inattentional blindness and working memory capacity, and how it is argued that low working memory capacity is an integral factor for the propensity of inattentional blindness.

Inattentional Blindness

Inattentional blindness was originally defined as the inability to perceive an unexpected stimulus, in sight, due to attention being directed elsewhere (Mack & Rock, 1998). This definition was based on initial work where participants had to distinguish the longer line on a fixation cross, with the critical trial containing an unexpected square stimulus shown for 200ms and within 2 degrees of fixation. On average 25% of participants failed to report the square stimulus on critical trials, furthermore, when the objects on the stimulus screen were shifted, so that the square stimulus was now centred on fixation, 60%-80% of participants failed to report its presence (Mack & Rock, 1998, see also Koivisto, Hyönä, & Revonsuo, 2004). Follow up work implicated visual and cognitive factors in the incidence of inattentional blindness, such as attentional focus and increasing the semantic saliency or size of the distractor (Mack & Rock, 1998).

The original inattentional blindness screening task has been developed into a more dynamic stimuli, to mirror our everyday visual experiences. This was implemented by Simon and Chabris (1999, see also Chabris, Weinberger, Fontaine, & Simons, 2011), where based on a selective looking task (Neisser, 1979), participants had to count the number of basketball passes made by a particular team in a video. Tasked with either counting the number of passes (easy task) or the number of passes with sub-counts for the types of passes (hard task), results revealed that approximately half of participants failed to identify the unexpected stimulus when engaged in the primary task, with inattention increasing with difficulty. In the dynamic task, the unexpected stimulus was presented for 5 secs, therefore demonstrating that inattentional blindness was observed even when exposure duration was substantially increased (Mack & Rock, 1998).

Previous inattentional blindness work that is most relevant to the thesis, however, was conducted by Most and colleagues (2001). A more controlled inattentional blindness screening task was created, with a number of Ls and Ts moving across the display. During this display, a cross of varying luminance moved in a transverse fashion across the centre of the display taking 5 seconds to move from one side to the other. Results showed a substantial role for similarity, when the luminance of the unexpected stimulus was similar to the attended items rates of noticing were higher, suggesting a role for attentional set (see Becker & Leinenger, 2011; Most, Scholl, Clifford, & Simons, 2005; Simon & Chabris, 1999). When the unexpected stimulus was changed to a red cross, noticing rates were recorded at 72%, suggesting that even though the distinctiveness of the stimulus was increased, compared to black or white, noticing rates did not significantly differ.

Whilst there has been documented roles for the level of expertise (Furley, Memmert, & Heller, 2010), attentional inhibition (Bressan & Pizzighello, 2008; Thakral & Slotnick, 2010), and termination of processing after task demands are met (White & Aimola Davies, 2008), an important factor in relation to this thesis is the role of semanticity. When the unexpected stimulus was replaced by stimuli that are prioritised as being more important on a semantic level, for instance bodies or faces, noticing levels were significantly better (Deuve, Laloyaux, Feyers, Theeuwes, & Brédart, 2009; Downing, Bray, Rogers, & Childs, 2004). Inattention rates reduce when faces match the mood of the participant (Becker & Leinenger, 2011), and the influence of semantic salient stimuli supersedes the effect of greater load (Koivisto & Revenso, 2009).

However, although the influence of semanticity has been investigated in relation to inattentional blindness rates, it is unclear whether sensitivity to such effects is participant-wide or not. This is to say whether such effects are dependent on capacity resources of the individual. Early research looking into expertise (Furley et al., 2010) does hint at a capacity explanation, with experts not needing as many resources for the primary task, therefore freeing up resources for the noticing of the critical stimulus. If the freeing up of working memory resources decreases the propensity for inattention, then those individuals that have greater capacity stores to begin with should, in theory, show smaller rates of inattention. This link is discussed in greater detail further on as the following section will introduce the concept of working memory capacity.

Working Memory Capacity

Whilst a wealth of research encompasses models of general working memory, the following section will specifically address research that carry links to capacity measures and limits in visual processing. The definition used in this thesis for visual working memory is taken as 'the active maintenance of visual information to serve the needs of ongoing tasks' (Luck & Vogel, 2013, p. 1), where specifically the representation of the information, not just the processed stimulus, must be visual. This can differ from reading for instance, where the representations of words are semantic, and separate from the visual properties of the printed text (Hollingworth & Luck, 2008). Furthermore, two more requirements that are made are that the representation must be one of a sustained, active nature, and that the representation must in turn be used for the processing of a broader cognitive task.

One robust visual working memory finding that is relevant to this thesis is the linking of neural components with behavioural capacity limits. Research using a change detection task, where participants have to maintain visual representations of targets over a delay interval in order to assess any changes, have established a sustained neural activity (contralateral delay activity: CDA) that reflects the number of items being maintained (Vogel & Machizawa, 2004; Vogel, McCollough, & Machizawa, 2005). Not only was this activity modulated by the number of targets held in visual working memory, but also reached an asymptote at the differing capacity limits for participants (Vogel & Machiwaza, 2004). This plateauing of sustained neural activity is congruent with behavioural capacity limits of three to four in visual working memory (Luck and Vogel, 1997; Cowan, 2001).

The exact nature of these capacity limits has been debated over the years, with the two main opposing sides proposing a discrete, fixed slots model (Alvarez & Cavanagh, 2004; Awh, Barton, & Vogel, 2007; Barton, Ester, & Awh, 2009; Cowan, 2000; Cowan & Rouder, 2009; Luck & Vogel, 1997; Zhang & Luck, 2008), or a more flexible resource-based model (Bays, 2009; Bays & Husain, 2008). However, what is agreed upon is that individual capacity limits exist, and limits can be indexed through a number of working memory tasks (see Chapter 2). The associations of such limits have been argued to have manifestations in experienced phenomena such as inattentional blindness, with individuals with lower working memory capacity carrying a higher susceptibility for inattention. This link will be discussed in the following section, with research supporting the link as well as research that argues capacity limits is not a reliable predictor.

Inattentional Blindness and Working Memory Capacity

The first experiment focuses on the relationship between working memory capacity and inattentional blindness, by testing the resource-based hypothesis of inattentional blindness for real-world stimuli. The role of working memory capacity was implicated in inattentional blindness by Richards, Hannon, and Derakshan (2010), where participants completed the operation span task (OSPAN), and later the automated operation span task (AOSPAN), a global/local flicker task based upon work of Austen and Enns (2000), and the inattentional blindness screening task used previously (Most et al., 2001; Simons, 2003), with the unexpected stimulus being the red cross. Results suggested that lower working memory capacity was associated with inattentional blindness, with the authors suggesting that available resources are the determining factor in whether an individual is able to process unexpected stimuli. Once an individual has reached their limit then there is no further processing of unexpected stimuli irrespective of whether than unexpected stimulus is relevant or irrelevant to the task. This therefore increases the propensity for inattentional blindness with individuals that have fewer working memory resources, giving rise to the resource-based hypothesis of inattentional blindness.

However, within the study a minority of participants classed as inattentionally blind scored highly on capacity tests, whilst this can be put down to variance, the authors suggested a dual-route model of inattentional blindness. Here higher working memory capacity participants can also elicit inattentional blindness tendencies, as they actively inhibit the irrelevant stimulus. This is supported by research showing greater distractor inhibition by individuals with higher capacity (Vogel et al., 2005). Although there is support for a potential mechanism for high working memory capacity participants eliciting inattentional blindness, the one-trial nature of the screening task makes it difficult to assess how replicable the phenomenon is in the same individual. However, if attentional blindness is seen as a propensity as opposed to a concrete trait, then working memory capacity can be seen as factor that alters the propensity.

This link between working memory capacity and inattentional blindness, including the dual-route model, has been replicated through indexing working memory capacity by the OSPAN task, but not through visual working memory capacity (Hannon & Richards, 2010). Given that the OSPAN taps into mechanisms such as goal maintenance, research is suggestive that lower working memory capacity individuals elicit a number of behaviours that ultimately give rise to an increased propensity for inattentional blindness. An example of such behaviours are fixations, where individuals that elicit inattentional blindness also elicit a less efficient fixation pattern during the screening task (Richards, Hannon, & Vitkovitch, 2012). With a greater number of fixations on distractors, both in terms of frequency and durations.

The mechanism of how higher working memory capacity individuals can elicit inattentional blindness has been linked to the relevance of the unexpected change in the screening task (Richards, Hannon, Vohra, & Golan, 2014). Results here showed that the nature of the change of the unexpected stimulus was only important for individuals with higher capacity. An inattentional blindness screening task was used where the change was either the red cross (task-irrelevant) or a change in one of the targets (task-relevant), with higher AOSPAN scores associated with the better strategy for each instance – inhibiting the task irrelevant change and processing the task relevant one. This flexibility in approach is also supportive of the dual route model of inattentional blindness, where although working memory capacity is a predictor of the incidence of inattentional blindness, high-capacity participants can both inhibit or process the change depending its task relevance (see Figure 1.1 for graphical representation).

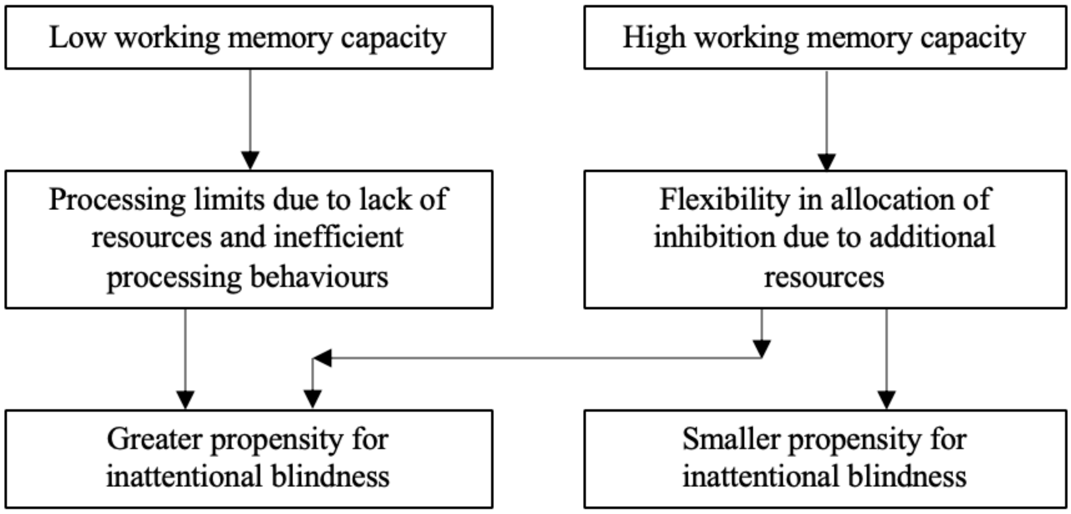


Figure 1.1. Graphical representation of the resource-based hypothesis of inattentional blindness, including the dual-route model, with added mechanisms.

However, whilst work in this thesis does begin with replicating the link between working memory capacity and inattentional blindness, the overarching aim of the first chapter was to assess whether sensitivity to semantic incongruencies in real-world images differ as a function of inattentional blindness. Recent research in inattentional blindness has laid a framework of neural differences in visual search paradigms (Papera, Cooper, & Richards, 2014). The visual search paradigm used a novel method of modulating saliency in stimuli. The model, based upon work from Itti, Koch, and Nieber (1998), created a saliency map from input images by extracting luminance contrasts and orientation filters in order to feed the numerical estimates into a 'genetic algorithm'. This algorithm used the saliency model as a fitness function in an artificial process of selection to create unbiased stimuli with varying levels of salience within a threshold. These visual displays consisted of artificially generated 'Randmorphs', a form of texton which are used to create texture segregation images.

These images were presented to individuals categorised through the inattentional blindness screening task, with inattentionally blind participants showing less sensitivity to changes in saliency. This lack of sensitivity was replicated when exposure times of images were shortened to one second (as opposed to 10 seconds), suggesting that inattentional blindness differences still persist with the lack of strategic top-down processing. The results therefore suggest that differences emerge at early stages of visual processing. A follow up study used the Randmorph task with EEG methodology to assess whether an inability to allocate resources at an early stage of processing led to unexpected stimuli from gaining access to working memory (Papera & Richards, 2016). Using a slightly altered version of the inattentional blindness screening task, where the unexpected change is induced upon a target as opposed to an ambiguous addition stimulus, the study replicated behavioural effects that inattentionally blind participants required higher saliency patches in order to match performance of non-inattentionally blind participants.

Furthermore, inattentionally blind participants elicited a more negative N1 component when patches were undetected compared to detected, suggestive of inefficient allocation of resources, as despite the larger amplitude, detection of the patch was not guaranteed. Moreover, theta band power was seen to significantly predict the probability of inattention (Papera & Richards, 2016), where greater theta power was indicative of more negative N1 amplitude. The same paper also observed greater target enhancement (N2pc) in non-inattentionally blind participants compared to inattentionally blind when saliency was low, but with no main effect of saliency, suggesting that differences are more due to group differences as opposed to general saliency differences. The lower target enhancement followed the poor allocation of resources in the N1 range for inattentionally blind participants, whereas extra amplification in the N1 range when targets were detected for non-inattentionally blind participants resulted in greater target enhancement in the N2pc (see Figure 1.2 for representation and added column for research progressions aims of this thesis).

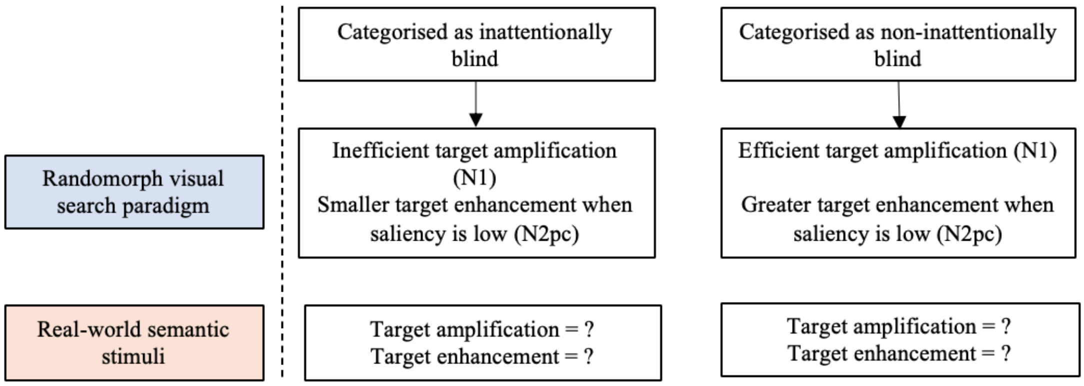


Figure 1.2. Representation of differing neural activity in inattentional blindness, with added empty row denoting early aims of the thesis.

These results are concomitant with Dehaene and Changeux's model of the Global Network Workspace (2005; 2011). The theory suggests stimuli can be covertly processed but without reaching conscious awareness, strong temporary increases in synchronised neuronal firing may induce a coherent state of activity. This activity may in turn compete with rather than facilitate the processing of visual stimuli, however, whilst very high spontaneous activity is a cause for competition, levels that slightly exceed normal help with the detection of weak stimuli (Dehaene & Changeux, 2005). There is therefore a clear rationale to assess whether differences in inattentional blindness are also evident in stimuli that closer represent the real-world. This is pertinent given that methods across the investigation of inattentional blindness have differed from more artificial stimuli, such as the screening task (Papera et al., 2014; Papera & Richards, 2016), to more real-world examples

(Chabris et al., 2011; Simons & Chabris, 1999; Simons & Schlosser, 2017). Furthermore, practical application of the research, and the resultant real-world implications of inattentional blindness, such as vigilance roles in airport traffic, occur in real-world settings. Therefore, research must carry a greater ability to translate to such settings.

Further neural differences have also been documented across inattentional blindness, and whilst they are not specific to sensitivity to images, they are still pertinent to the early aims of this thesis. Papera and Richards (2017) observed that mean amplitude in the CDA range was predictive of the level of inattention in a change detection task. The change detection task requires participants to essentially maintain representations of targets during an interval period, and then assess any changes to the targets after the interval. Inattentionally blind participants showed lower CDA amplitudes during the interval period for higher set sizes, suggestive of a decreased ability to maintain representations. Furthermore, levels of CDA amplitude showed no difference over set sizes for inattentionally blind participants, suggesting an earlier saturation point when compared to the increasing, more flexible amplitudes for the non-inattentionally blind. Research therefore reflects a mirroring of later behavioural differences in flexibility (Richards et al., 2014) in early EEG components.

Work in this thesis will also indirectly address the debated link between working memory capacity and inattentional blindness. The incidence of inattentional blindness has been attributed to the demands of the primary task, instead of individuals' ability to meet the demands (Simons & Jenson, 2009). The predictive nature of the AOSPAN has also not been found to be consistently significant (Kreitz, Furley, Memmert, & Simmons, 2015), as have other tests of spatial working memory

(Bredemeier & Simons, 2012). Other factors such as attentional set have been found to influence the rate of noticing the unexpected change as opposed to working memory capacity differences (Kreitz, Furley, Memmert, & Simons, 2015b).

Furthermore, whilst previous opposing research have included a number of pre-critical trials before the unexpected stimulus appeared on a critical trial, Beanland and Chan (2016) tested the no-practice condition that has been shown to produce some links to working memory capacity. When entered into a logistic regression, no predictive power of AOSPAN on the level of noticing was found, either in the full dataset, or using the approach of Seegmiller et al. (2011), where participants that only correctly counted the number of bounces were included. Despite evidence for and against the role of individual differences, it is notably difficult to study such a phenomenon due to the one trial nature of the paradigm. Even evidence that attempts to link inattentional blindness categorisation to performance on other tasks (Papera et al., 2014; Papera and Richards, 2016; Papera and Richards, 2017) do so on the back of a one critical trial.

Lastly, in the inattentional blindness screening task participants are shown the critical trial for a second time, with no requirements of the primary task. This full-attention trial serves the purpose to exclude participants that do not observe the unexpected stimulus even when there are no primary task demands. Results from a literature search conducted by White, Davies, and Aimola Davies (2018), illustrate variance in whether a full-attention trial in implemented in the literature. This is firstly problematic in comparing results where participants are excluded due to not noticing the unexpected stimulus on the full-attention trial to studies that do not implement it. Furthermore, in cases where it is, the authors argue that participants that do not notice the unexpected stimulus may be eliciting high levels of inattentional blindness, as in conditions where the rate of inattentional blindness is high on the critical trial, rates of inattentional blindness on the full-attention trial is also high (White et al., 2018).

Therefore, whilst opposing research does provide a strong account that inattentional blindness is due to stochastic factors as opposed to a consistent working memory capacity-based trait, there are issues in comparing studies that do not implement the same screening task procedures. The first empirical chapter will therefore look to replicate the link between working memory capacity and inattentional blindness, but also replicate findings that inattentional blindness categorisation predicts differing levels of sensitivity to image textures, but with a move to more real-World images.

1.4 Links to Object Tracking

The following section will outline the reasons, together with relevant literature, behind linking early work conducted in this thesis to mechanisms of single and multiple object tracking. Investigations into inattentional blindness have involved a screening paradigm to categorise participants into whether they notice the change or not. These screening paradigms have essentially maintained the same parameters: tracking a number of stimuli with the delayed presence of an unexpected stimuli or change. This has ranged from static stimuli with the presence of a cross (Mack & Rock, 1998), dynamic targets and distractors with a dynamic cross (Most et al., 2001) or change to a target (Papera & Richards, 2016), and even counting basketball passes with the unexpected presence of a man in a gorilla costume (Simon & Chabris, 1999). One consistent theme has been the requirement to track either a solitary or a number of targets.

Work in this thesis progressed from investigating differences in inattentional blindness by examining sensitivity to real-world textures, to potential differences in tracking mechanisms and strategies across working memory capacity. The rationale for this transition is based on the requirement for participants to actively track during the inattentional blindness screening task. Therefore, the link between inattentional blindness and working memory capacity could be elucidating through investigating tracking differences across working memory capacity. Given that tracking itself is a multi-faceted behaviour, the implementation of tracking, and efficiency or consistency of tracking, may provide insights as to whether the link between inattentional blindness and working memory capacity is purely down to a limit in resources, or whether how the primary task of tracking is carried out – due to working memory capacity differences - that ultimately affects the propensity of inattention.

Object Tracking and Implicated Mechanisms

The implications of object tracking to inattentional blindness is a research area that has yet to be completely understood. Whilst a plethora of research has been conducted in both single object tracking, such as mechanisms of smooth pursuit, and multiple object tracking, with the multiple object tracking task (MOT), work in this thesis aims to investigate whether existing mechanisms can be isolated across different levels of working memory capacity. This would then in turn shed on light on whether different tracking approaches are being employed, which could influence rates of inattention by freeing up additional resources. One key mechanism that has been established and is investigated in this thesis is the role of extrapolation of target trajectories.

The role of predictive processes has been investigated in the MOT paradigm, alongside the sole use of location information (remembering where targets were last seen). Performance in the MOT has been found rely on location information when targets are occluded (Keane & Pylyshyn, 2006), with superior performance when objects reappeared at the at locations prior to occlusion compared to extrapolated positions. However, it has been proposed that the extrapolation of trajectories can be a beneficial compensatory mechanism to counter the processing delay of tracking visual objects (Nijhawan, 2008). This therefore carries pertinent links to a paradigm such as the inattentional blindness screening task, as it may be the case that predicting trajectories is used as a compensatory mechanism to free up resources, for participants with lower working memory capacity. This is turn would increase chances for noticing the unexpected change, thus not reflecting a true inattentional state.

The role of predicting extrapolations was implicated somewhat in a later study (Fencsik, Kleiger, & Horowitz, 2007), here participants did elicit a tendency to use trajectory information to predict future locations. However, the tendency to use trajectory information was load dependent, with participants only doing so under lighter loads. The authors suggested that although the most common mechanism to tracking across a trial gap was to compare post and pre-occlusion locations, motion information is stored for lighter loads. Furthermore, the mechanism by which individuals track over an occlusion, coined ‘attentional high-beams’, has been proposed to require further attentional resources than simply tracking visible targets (Flombaum, Scholl, & Pylyshyn, 2008). Here participants allocated higher levels of attention to locations of occluders, as probe detection was superior when targets were occluded. Fencsik and colleagues (2007) propose that whilst active tracking may not occur during trial gaps, motion information is stored continuously during periods of visible motion in preparation for unpredictable breaks. However, what is unclear is whether employment of such a strategy is dependent on working memory capacity resources, which may be the case given that the active tracking of targets through occlusion requires greater resources.

Whilst motion information seems to be utilised when it is explicitly required, for instance in trial gaps or in the presence of occluded targets, the role of extrapolation in normal tracking is slightly less clear. Research has shown that that introducing incongruent, background motion impairs regular tracking (Huff & Papenmeier, 2013; St. Clair, Huff & Seiffert, 2010), this has been shown to be a product of object-based attention and not a cause of global interference (Meyerhoff, Papenmeier, & Huff, 2013). When measuring mouse-clicks as a representation of target positions, research have found individuals elicited a bias for future locations (Iordanescu et al., 2009), a finding replicated in a probe detection task (Atsma, Koning, & Lier, 2012). The benefit of predictable trajectories of objects has been found to be load dependent, namely, tracking predictable trajectories where extrapolation would be utilised is superior for lighter loads, when controlling for eye movements (Luu & Howe, 2015) and without (Howe & Holcombe, 2012).

This is also apparent in studies investigating smooth pursuit, where attentional resources have been observed to be allocated ahead of the tracked object (Khan et al., 2010). When using a data-driven approach, with no a priori assumption about gaze behaviour, researchers have found that gaze behaviour does exhibit a lag behind object movement in a MOT paradigm, which does however show some decrease with lower tracking loads and predictability (Lukavsky & Dēchtērenko, 2016). Lastly, research into computational modelling has illustrated the limited benefit of extrapolating target trajectories during normal tracking (Zhong, Ma, Wilson, Liu, & Flombaum, 2014). The researchers pose that this it is especially pertinent when extrapolation is based upon noisy input, given the inefficient early amplification seen in inattentionally blind individuals (Papera & Richards, 2016), lower working memory capacity individuals may in turn suffer from noisier input, resulting in less of a reliance on extrapolation.

Research has also hinted at a neural index of extrapolation in a MOT task, where the requirement to continuously monitor the spatial information of targets was manipulated by introducing pauses, stops, or compete inertia in the MOT paradigm (Drew, Horowitz, Wolfe, & Vogel, 2011). The researchers speculatively proposed that a 350ms delay in attenuation of the CDA amplitude, when objects are paused, could be reflective of a background predictive mechanism, where participants continue to predict trajectories in spite of the pause. Research in extrapolation therefore represents an unclear picture, it seems as though extrapolation can be used under lighter loads for target tracking, but the use of location information to estimate target locations is a preferential strategy, especially under greater loads. Whilst there is a greater demand on working memory capacity resources to actively track a target over a trial gap, whether this is then working memory capacity dependent, and whether this demand also applies to targets that are constantly visible in a dual task (such as the inattentional blindness screening task, where participants have to track in addition to count target bounces), are questions that later chapters in this thesis aim to answer.

1.5 Overview of Following Chapters

The following section will provide an overview for the following chapters presented in this thesis. The first of the experimental chapters, Chapter 2, builds upon work that investigates whether inattentional blindness is linked to sensitivity to incongruent visual patches (Papera et al., 2014, Papera & Richards, 2016), but in a real-world context. Chapter 2 presents two studies, the first which aims to standardise a set of novel stimuli, created through a form of image quilting, in order to be able to rank images on the basis of difficulty. The second study investigates whether these images, that contain patches that violate the semanticity of the image, are allocated varying levels of neural inhibition when presented as distractors, and whether the capability to do is dependent on the inattentional blindness classification of the participant. Measures of working memory capacity are taken to assess whether the incidence of inattentional blindness is related to the capacity of the individual.

Chapter 3 built upon work from the previous chapter by investigating a more systematic approach to introducing violated patches in images of texture. Whereas in the previous chapter the image quilting method produced a new image that contained violations throughout, with image difficulty then ranked on the basis of participant accuracy rates. The single study presented in Chapter 3 used a gap filling technique, of varying sizes, in order to create images on a more systematic basis. Chapter 3 again investigated the role of neural inhibition that is applied to distractor images, however, whereas previously the inattentional blindness classification of participants was used as a grouping factor, here analysis focused on working memory capacity. The robustness of classifying participants on the basis of a single trial exposure is discussed, as are the implications of the results to working memory capacity and inhibition.

The penultimate empirical chapter, Chapter 4, presents two behavioural studies that investigate the overt and covert tracking nature of individuals in a novel tracking task. The aims of the chapter were to assess whether individuals with lower levels of working memory capacity exhibit tracking tendencies that compensate for fewer resources. Whilst the first study presented in the chapter allows for free viewing during the task, the second attempts to restrict eye movements, the latter study in this chapter also transitions from observing grouped based results to modelling individual differences. Tracking behaviour is assessed through distance measurements both when trajectory of the target is predictable and unpredictable, with results discussed in relation to both theories of capacity and tracking but also how such results are related to the tracking nature of the inattentional blindness classification task.

The last empirical chapter, Chapter 5, presents three EEG studies that use the established MOT paradigm to investigate object tracking, furthermore, the analysis approach of investigating working memory capacity behaviour on a spectrum instead of grouping is continued from Study 4.2. The first study presented in the chapter investigates whether individuals with lower working memory capacity have the resources to predict target trajectories over a trial gap, or whether they merely maintain representations to estimate locations when required. The CDA is measured in this chapter in order to index the number of items held in working memory, and is investigated alongside measures of target load, object trajectory predictability, and accuracy.

The second study in Chapter 5 introduces a target load that requires tracking beyond standard capacity limits, whilst keeping all other parameters equal. Following on from the first study in Chapter 5, requiring participants to track beyond capacities would help to emphasise differences that are employed by individuals at varying levels of working memory capacity. The last study in Chapter 5 investigated whether there are differences in approaches that are employed over the time of an experiment. Target loads were presented in a blocked fashion and separated into each half of the study, analysis could therefore compare the change in the number of items tracked in each half and whether individuals with varying levels of working memory capacity changed in their approach to tracking. Lastly, the thesis concludes with a general summary of all results. The chapter will address the findings of each chapter and attempt to amalgamate them to consider the implications for the theories mentioned in this thesis. Furthermore, the implications of both results and the methods used will be discussed. The chapter will then end of potential future directions that research can continue on, and some concluding remarks for the thesis itself.

Chapter 2. Inattentional Blindness, Working Memory, and Image Quilting

2.1 Sensitivity to Image Quilting across Inattentional Blindness

2.1.1 Introduction

Research Question

The following study will present participants with an image discrimination task, where participants have to identify images as real or artificial, with the aim of categorising artificially created images into images that are easier to identify (high violation) or more difficult to identify (low violation). The stimuli and associated difficulty categorised in the current study will then be used in Study 2.2. This study also aims to investigate whether identification speed and accuracy of these images can be predicted by the inattentional blindness status of participants. The following sections will introduce the image quilting technique used, the research linking inattentional blindness to sensitivity differences to saliency in images, and the hypotheses for the study.

Image Quilting

Image quilting falls under the umbrella term of texture synthesis, which comprises of a number of methods that provides algorithmic process for creating textures. However, the texture should be perceived by individuals to have undergone the same underlying stochastic process in its manufacture (Wei & Levoy, 2000). Textures themselves have long been classified as a product of their regularity or stochastic nature (O'Brien, Wickramanayake, Edirisinghe, & Bez, 2003), with a vast majority of textures taken from the real world falling on a spectrum between these two points. These can vary from natural examples of fractal patterns such as Romanesco broccoli to more contrived instances such as brick walls. All points on this spectrum carry the same definition and one that is used in the production of textures in image statistics, that is, a texture contains a repeating pattern with a varying amount of random noise or variation.

Image quilting was used to produce artificial textures for the two studies in this chapter, with results from the first chapter being used to categorise the artificial images into high or low violation categories. The method used was based upon work by Efros and Freeman (2001), with the process steps described in the methods section (see section 2.1.2). This approach broadly starts with a randomisation of the input image, permitting the preservation of predefined image statistics. Other techniques approach texture synthesis in a similar way (Xu et al., 2000; Praun et al., 2000) but with the preservation of global statistics. However, techniques that aim to preserve global statistics may produce inconsistent results when images are a product of both structured and stochastic patterns.

The extreme opposite of enforcing statistics globally is local strategy, or a single pixel at a time, where a number of restrictions can occur. First, there is a greater tendency for erroneous production and secondly, there is a smaller degree of freedom with production, as the higher levels of complexity within the image means that fewer pixels have a variety of potential values assigned to them, meaning that there could be a restriction on the repositioning of them. Therefore, the approach of Efros and Freeman (2001), and one that is implemented here, is one of predefined patches. This method overcomes the two aforementioned limitations in the sense that image searching, and synthesis is not concentrated on pixels that have a predetermined result.

This approach is especially pertinent for the purpose of the work in this chapter, as a patch-based technique provides an image that can largely maintain semantic consistency, as images within a patch would be preserved. However, the approach can introduce violations through quilting together two patches that do not maintain semantic consistency across, for instance see the pineapple in Figure 2.1 where ripeness unnaturally changes. This is also apparent in other image examples given in Figure 2.2, where although the shape of the food type is continued, for instance half an apple being patched with another half, the overall shape of the apple looks unnatural.

Whilst image manipulation has been used to assess consistency effects (Mudrik et al., 2010; Mudrik et al., 2014), this has been on the basis of placing an image on top of a background image to introduce contextual differences, for instance an image of an iron placed on a background of woodland. Image quilting therefore provides an opportunity to introduce varying levels of semantic inconsistencies in textures, in a method that is more realistic to the environment, which can then be used to investigate differences in sensitivity to them. Furthermore, the image quilting process used in the current study produces an error value that is representative of the error in production of the quilted image. This is pertinent, as the foremost reason for Study 2.1 was to categories the quilted images into those that carry high and low levels of violations for Study 2.2. The error term therefore allows for a comparison of image categorisation difficulty by participants to the error term produced in image production, to assess whether there is congruency across this produced error term and the perceived violations by participants.

Inattentional Blindness

Inattentional blindness was originally defined as the inability to perceive an unexpected stimulus, that which was in sight, due to attention being directed elsewhere (Mack & Rock, 1998). The phenomenon has been well researched over the years, with a number of experimental parameters such as attentional set playing a central role in whether individuals notice the unexpected stimulus (Becker & Leinenger, 2011; Mack & Rock, 1998; Most, 2013; Simons & Chabris, 1999). However, one debated topic of research is the role of the individual's working memory capacity in the incidence of inattentional blindness. Certain research has suggested at a capacity-based explanation for inattentional blindness, with low working memory capacity individuals showing a higher propensity to inattentional blindness (Hannon & Richards, 2010; Richards et al., 2010; Richards et al., 2012; Richards et al., 2014; Papera & Richards, 2016; Seegmiller et al., 2011).

This capacity-based explanation suggests that lower working memory capacity individuals carry a higher propensity to inattentional blindness due to a smaller resource pool, where in demanding visual environments, resources are used up and consequently unexpected stimuli are not processed to conscious awareness due to the inability to allocate any resources. This theory has been supported through behavioural and EEG data, where inattentional blindness participants have been found to elicit less sensitivity to change in saliency in a low-level visual discrimination task (Papera et al., 2014). Furthermore, inattentional blindness participants have been shown to elicit poorer allocation of resources in the N1 range, followed by poorer target enhancement in the N2 range, when compared to non-inattentionally blind participants (Papera & Richards, 2016).

However, in spite of evidence linked working memory capacity to different capacity levels and neural signatures, a number of studies have demonstrated that a capacity-based hypothesis reflects a weak, if at all, link to inattentional blindness (Beanland & Chan, 2016; Bredmeier & Simons, 2012; Kreitz et al., 2015a; Kreitz et al., 2015b). Due to this contested link between working memory capacity and inattentional blindness, capacity scores of participants were recorded in this study to observe if they could predict the incidence of inattentional blindness. While the link between capacity measures and inattentional blindness is controversial, there is strong evidence that individuals that elicit inattentional blindness different behavioural and neural responses to salient patches in visual search (Papera et al., 2014, Papera & Richards, 2016) – research that this study is seen as a continuation of.

Such previous research estimated saliency through the computation of orientation and luminance scales (Papera et al., 2014), which are fed into an algorithm to produce patches of saliency in a display of textons. Textons are defined as fundamental elements in visual perception that form texture segregation images (Julsz, 1981; Papera et al., 2014). With inattentional blindness participants requiring a higher level of saliency for low-level features in order to identify these texton-based target patches (Papera et al., 2014). However, whilst such research manages to investigate inattentional blindness in a systematic manner, inattentional blindness in the real world is subject to stimuli that contain complex, semantic information. Work in the current chapter therefore investigates inattentional blindness with stimuli that contain semantic information, and where saliency is not a product of low-level features such as orientation, but one where processes such as matching to existing schemas take place, as they would in a real-world setting. It is argued here that the image quilting method allows for such an investigation, and that through the utilisation of the technique, it can be investigated whether low-capacity individuals experience inattentional blindness also show less sensitivity to semantic violations in real world images.

Rationale

The main rationale of the study was to obtain accuracy responses in order to categories the artificially created stimuli for Study 2.2, which in turn investigated the neural inhibition allocated to the different categories of image violation. However, here measures of capacity were also taken in order to investigate whether they predicted the occurrence of inattentional blindness. Additionally, given research has shown that inattentionally blind individuals react slower to identifying salient patches (Papera et al., 2014), the reaction time and accuracy measures provide a means to test whether an inattentional blindness trait is linked to less accurate and slower processing of artificial stimuli.

Hypotheses

The hypotheses will be formally stated in order that foreshadow the analyses; to begin with, it was predicted that participants that elicit inattentional blindness will attain lower capacity scores in the working memory capacity test (Corsi Block Tapping Task: CBTT) than those that do not elicit inattentional blindness. Participants that elicit inattentional blindness will also show less accuracy and slower reaction times on the image discrimination task when classifying images as artificial or real. For the last two analyses, no a priori predictions were made, as the median split of the images based on accuracy were for categorisation in Study 2.2, and the correlation with error rates were to assess whether accuracy was linked to the error value produced in the production process of the images.

2.1.2 Methods

Participants

A total of 24 participants were recruited using a cloud-based participant management software. All had normal or corrected to normal vision and were naïve to the experimental hypotheses. All experimental procedures were approved by the Birkbeck research ethics committee, and informed consent was taken before testing. Participants were excluded through ambiguous answers to inattentional blindness probes (no participants excluded), less than 50% accuracy of hits on the inattentional blindness screening task (no participants excluded), no observation of the change in the full attention inattentional blindness trial (no participants excluded), or non-compliance on the CBTT (one participant excluded). The remaining 23 participants were aged between 19 - 50 (M = 29.2, SD = 11.3).

Image Discrimination Task – Stimuli

The image discrimination task was coded using MatLab (Mathworks) and the Psychtoolbox extension (Brainard, 1997; Pelli, 1997; Kleiner, Brainard & Pelli, 2007), the monitor used was a Samsung SyncMaster 2233, with display measurements of 1920 x 1080, with a viewing distance of 60cm. When presented the image subtended to 9.5° across and 7.5° high, with the fixation cross subtending to 0.9 x 0.9°. Images for the image discrimination task were collated using the Google search engine, and images of food were solely selected to avoid any bias of category, resulting in 100 images.

The image quilting MatLab code was then run on each image to produce an artificial pair, this began through the selection of a random patch (measuring 160 x 160 pixels) of the source image, which would be placed in the top left corner of the output image. The size of each new patch was consistent (160 x 160 pixels) and the output image had five patches across each axis. A new neighbouring patch was then searched for in the source image, with the squared pixel distance between the existing patch computed at each search iteration. All new patches where the squared pixel distance complied with the error tolerance were grouped together, with the error tolerance set at 0.1 in the formula (1.1 times the error of the best matching block):

$$(1 + error) * Best_{Distance}$$

A random patch was selected from these patches that comply with the error tolerance and was placed alongside the existing patch with an overlap of 1/6 of the size of the patch. This overlapping error surface was defined as:

$$e = (B_1^{ov} - B_2^{ov})^2$$

Where if B_1 and B_2 represent the two blocks that were placed as neighbours, $B^{ov}{}_1$ and $B^{ov}{}_2$ represent the overlap regions for each image. The minimum error boundary cut was then made in this overlapping area, where the squared pixel values in each cell of a single row of the error surface were compared using the L2 norm on pixel values function in MatLab. This function isolated the two corresponding cells in a single row for each patch in the overlap region that presented the least amount of error.

The comparison for each row resulted in a vertical path that represented the least amount of error in the overlapping region. The path of least error was then traced backwards, and a cut was made through the overlapping error surface, creating the new boundary between the patches and thus quilting the patches together (see Figure 2.1 for a visualisation of the process and an example image pair). This process was then repeated for each new patch, until the output image reached the defined size.

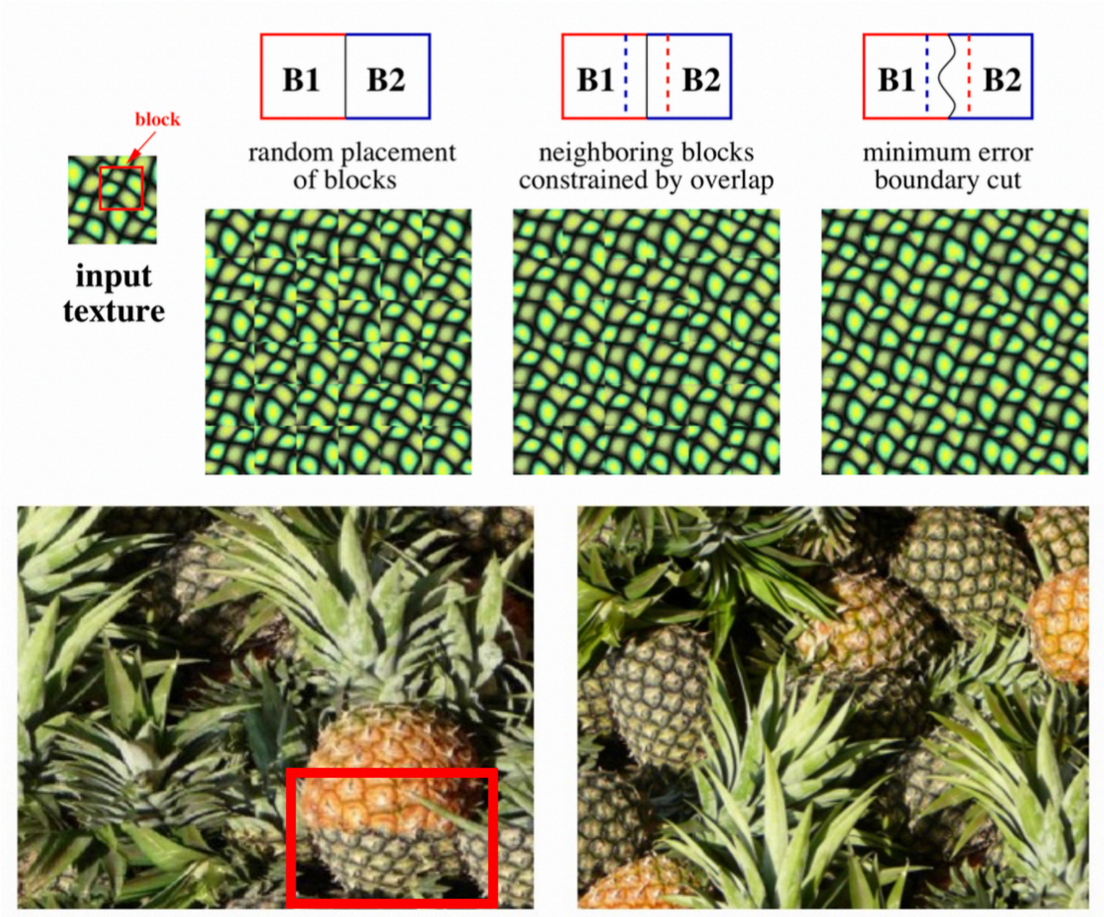


Figure 2.1. Top: Image quilting process. Source: Image taken from Efros and Freeman (2001). Bottom: An example stimuli pair, with the synthesised image (left) and the original input (right), distortions can be observed in the bottom right-hand corner of the image where the ripeness of the pineapple is unnaturally changed mid-object, outlined by red square.

Average error rates, defined as the average best squared distance for each new patch, were collected for each image to serve as a process-based indicator for error. Additionally, a five-by-five matrix of each best squared distance per patch was collected (see Figure 2.2 for more example pairs and example matrix overlaid on image). In total 100 artificial images were produced, each having a natural image (the source image). Furthermore, in order to control for effects of picture quality, visual noise was placed on each image through the *imnoise* MatLab function. Where noise is added to the image by multiplying the image matrix with uniformly distributed random noise, with mean zero and a consistent variance of 0.015.

Figure 2.2. Images illustrating the texture synthesis process, with the source images in the left column and the synthesised outputs in the right. The overlay table at the bottom right of the figure denotes the five-by-five error matrix.

Image Discrimination Task – Procedure

The image discrimination task was shown to participants first and began with a practice session of 20 trials, which were identical to the main experimental trials. A trial began with a central fixation cross (500ms), which was then replaced by random image shown centrally for either 10 seconds or until user input (see Figure 2.3). Participants were required to distinguish, as quickly as possible, whether the image presented was real or artificial. This was entered through either the ‘r’ or ‘c’ keyboard keys. Participants were not given information on how the quilting process was performed and were instructed to decide based on a degree of naturalness. A sample of 100 images were shown from the 200 images sample to ensure that participants could not mentally compare the synthesised with the source image in order to aid performance.

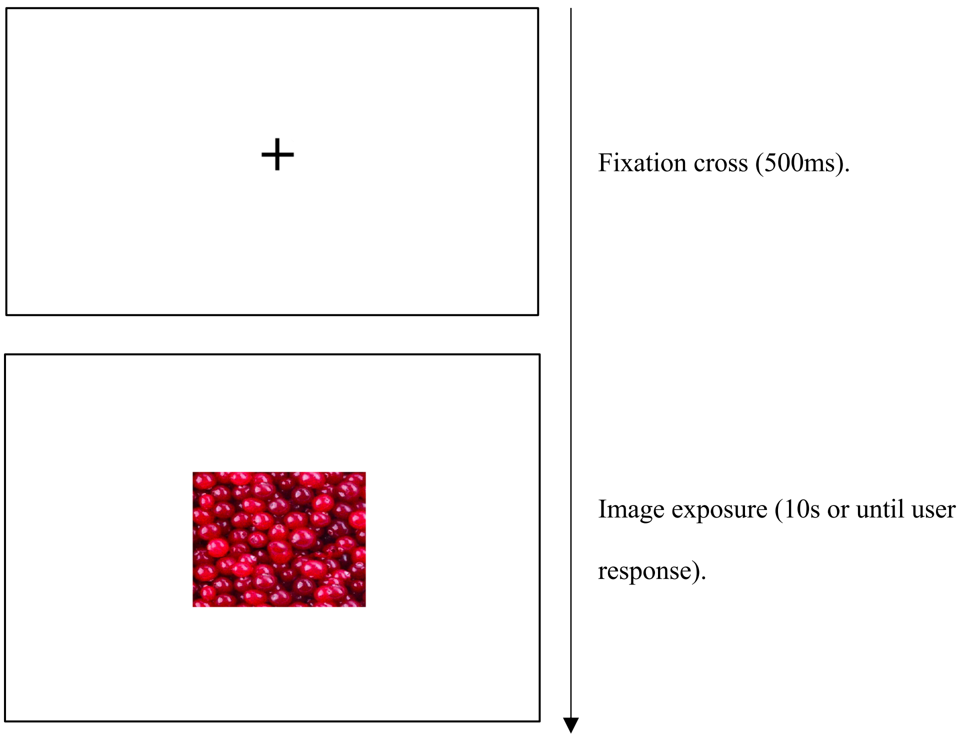


Figure 2.3. Example trial from the image discrimination task.

Image Discrimination Task - Factors

The independent variable in the image discrimination task was the image nature, either real or artificial. Measures of accuracy on image categorisation and reaction times were taken for each trial. The median of accuracy rates across images would be used to split the images into high and low violation images for Study 2.2.

Image Discrimination Task - Relevance

The function of the image discrimination task was to categorise the artificially produced images from the image quilting method into either a high or low violation category for Study 2.2. Images that produced accuracy rates above the median (median to 100%) were categorised as high violation as they were easier to correctly identify, whereas images that produced accuracy rates below the median (median to 0%) were categorised as low violation as they were more difficult to identify. However, an analysis of accuracy rates and reaction times across levels of inattentional blindness was also performed, as differences have been found with low-level image stimuli (Papera & Richards, 2014).

Corsi Block Tapping Task - Stimuli

The visual working memory task employed was the computerised version of the CBTT, which was run on PEBL software (Meuller & Piper, 2014) but based on the standardisation of Kessels, van Zandvoort, Postma, Kappelle, and de Haan (2000). A Samsung SyncMaster 2233 monitor was used, with display measurements of 1920 x 1080, with a viewing distance of 60cm. The blocks presented on screen measured 90 x 90 pixels, subtending to 2 x 2° of visual angle. Nine navy blue blocks were placed in random, but not overlapping, locations. While the colour of the blocks was consistent across participants, the spatial arrangement was not. Although Kessels et al. (2000) described standard locations for the CBTT, using the same locations may have introduced practice effects for participants who have completed the CBTT previously. Squares that were randomly selected for the trial sequence were done so by lighting the in a pale-yellow colour for 1000ms.

Corsi Block Tapping Task - Procedure

Participants completed the CBTT second, which started with a practice session of three trials, each with a sequence length of three, the procedure of which were identical to the main experimental trials. The main experiment trials started with an exposure screen of all squares in locations for 1000ms. The first square was then highlighted in a pale-yellow colour for 1000ms, and then onto the next random square in the sequence. The task began at a sequence length of two. Participants used the mouse to click on the squares in the sequence that they were shown. Two iterations of each length were shown consecutively, if at least one of these sequences were recalled correctly (by clicking on the squares using the computer mouse), then the next two trials would increase in length by one, with a maximum sequence length of nine (see Figure 2.4 for example sequence). The test was terminated once the participant was unable to recall two sequences of equal length. Although sequence patterns are given by Kessels et al. (2000), here they were randomised in order to eliminate any sequence learning that participants may have done if they had completed the task previously.

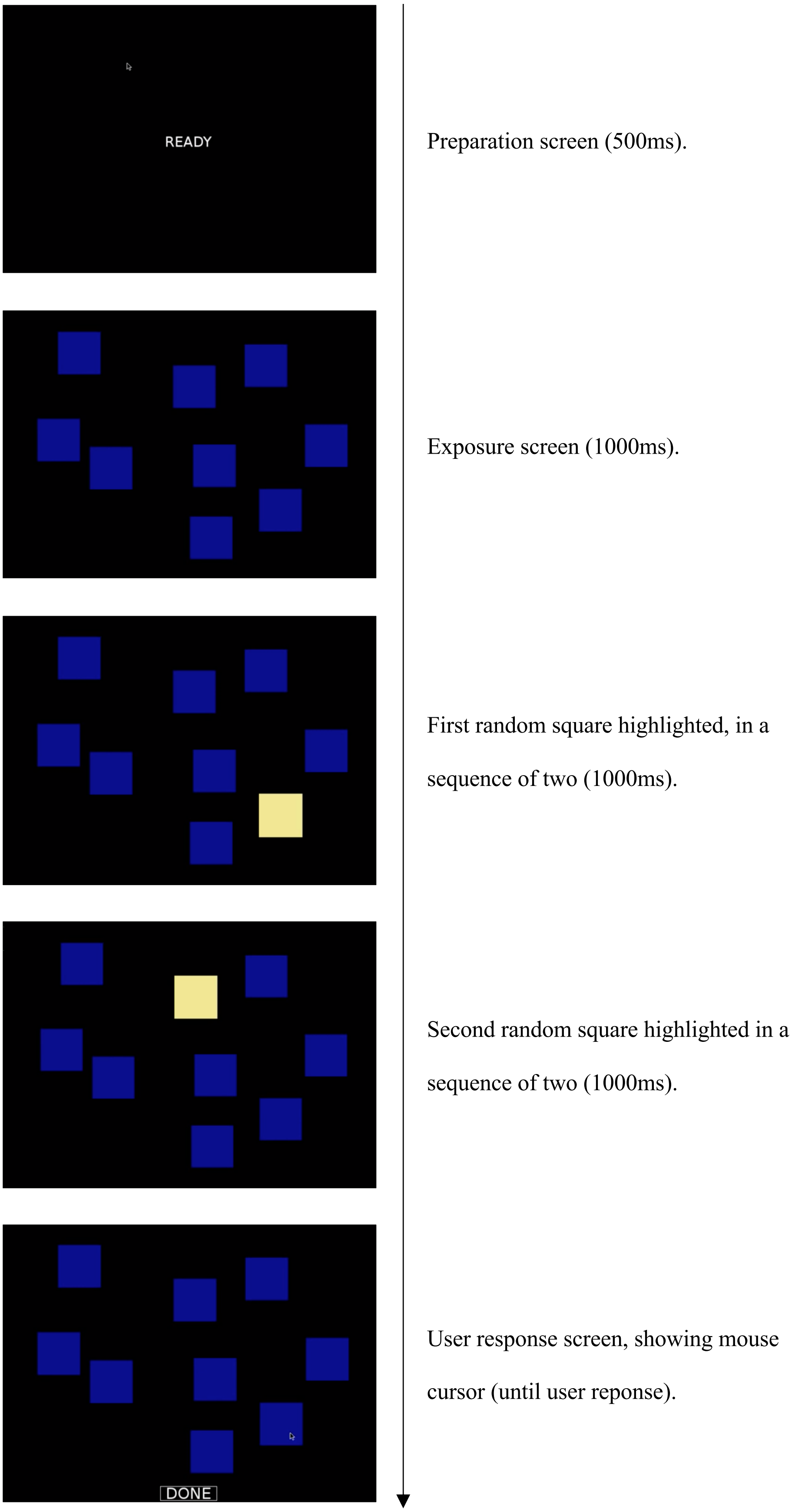


Figure 2.4. Example two square sequence for the Corsi Block Tapping Task.

Corsi Block Tapping Task - Factors

Scores of block span were computed for each participant, through measuring the length of the last correctly recalled sequence, and therefore could vary from two to nine.

Corsi Block Tapping Task – Relevance

The CBTT has been shown to be a robust measure of visuospatial short-term memory and was therefore used to index working memory capacity of participants in order to predict levels of inattentional blindness.

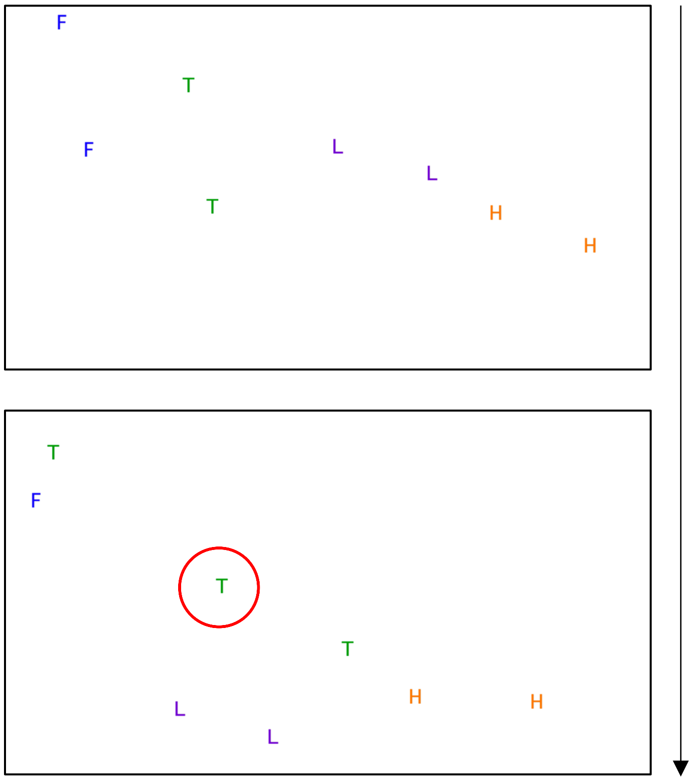
Inattentional Blindness Screening Task - Stimuli

The inattentional blindness screening task was coded using MatLab (Mathworks) and the Psychtoolbox extension (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007), and was based upon previous inattentional blindness literature (Papera & Richards, 2016). The monitor used was a Samsung SyncMaster 2233, with display measurements of 1920 x 1080, with a viewing distance of 60cm. The inattentional blindness task consisted of eight letter stimuli categorised into groups of two, each subtending to 0.7° across at the widest point, and 1° in length. Stimuli moved at a rate of 3.5°/s and rebounded off the screen edges in a random fashion, but not off one another with brief occlusion possible. The eight letter stimuli consisted of two green 'T's, two blue 'F's, two orange 'H's, and two purple 'L's. The green 'T's and blue 'F's constituted the targets and the other two groups the distractors, target groups and stimuli colours were kept constant across participants.

Inattentional Blindness Screening Task – Procedure

The inattentional blindness screening task was shown last, this was due to the unpredictable change included within the task. Whereby if participants completed the inattentional blindness screening task before other tasks, the unexpected change may cause them to anticipate a non-existent change and not focus on actual task demands. The inattentional blindness screening task itself did not include a practice session, instead participants were shown an instruction screen and given verbal instructions. Participants were told that on screen eight letter stimuli would appear, and that the two green ‘T’s and two blue ‘F’s make up the target letters, whilst the two other groups (two orange H’s and two purple L’s) constitute distractors. The task would be to mentally tally how many times the target letters bounce off the edges of the screen, and that they would be verbally probed on the answer after the trial finished.

The inattentional blindness screening task was started by the participant once ready. All eight letter stimuli were pseudo-randomly distributed on the screen, and movement commencing immediately. Placement of stimuli, the trajectories, and consequently the correct answer to the probe (12 hits), were consistent across all participants. The task ran for 26 seconds, and at the halfway stage (13 seconds), one blue ‘F’ changed into a green ‘T’ (see Figure 2.5 for trial sequence and letter change). After the trial was complete, subjects were probed as to the total number of counted hits and whether they had noticed any peculiar occurrence in the display. Classification of inattentional blindness was dependent on their ability to notice the target switch. The task was shown again without the target counting requirement (full-attention trial), to ensure that participants could observe the switch when attention was not otherwise engaged.



Beginning of inattentional blindness screening task, with all letter stimuli present.

Target letter change at the halfway stage (13s), where one blue ‘F’ changes into a green ‘T’.

Figure 2.5. Example trial from the inattentional blindness screening task, the red circle highlights the target letter change.

Inattentional Blindness Screening Task - Factors

The inattentional blindness screening paradigm was a classification task, therefore the change (blue ‘F’ to green ‘T’) occurred for every participant. Measurements of accuracy on the number of times the target letters bounced off the screen edge were taken, in addition to whether participants noticed the unexpected target letter change. After the task participants were asked “was there anything unexpected that you noticed in the duration of the trial?”. If participants answered the probe correctly with a description of the change they were classified as non-inattentionally blind, if they stated that they did not notice anything they were classified as inattentionally blind. Any ambiguous answers to the probe resulted in participants being excluded from the study, as did a lack of perception of the change in the full attention trial, although no participants fell under either category.

Inattentional Blindness Screening Task - Relevance

The relevance of the inattentional blindness screening task was to classify participants into those that elicit the tendency of inattention (IB participants) and those that do not (NIB participants). The test involved one change of a blue ‘F’ target into one green ‘T’ target (Papera & Richards, 2017) as opposed to a red cross that transverses across the screen (seen in Most et al., 2001; Simmons, 2003). This was due to the ambiguous nature of the cross that may lead to a bias to either process or inhibit the additional stimuli due to its irrelevant nature. The lack of processing of an unexpected change to an existing target therefore would reflect the inattentional blindness phenomenon clearer.

2.1.3 Results

Capacity Differences Across Inattentional Blindness

An independent t-test was run across the two groups (inattentionally blind/IB participants = 15, non-inattentionally blind/NIB participants = 8) and the block span score from the CBTT to investigate differences in capacity across inattentional blindness groups. Post hoc power values were computed using G*Power (Faul, Erdfelder, Lang, & Buchner, 2007). Capacity scores between groups did not significantly differ, IBs (M = 5.86, SD = 1.55), NIBs (M = 6.62, SD = 1.51), $t(22) = 1.22$, $p = 0.28$, $d = -0.49$, power = 0.11.

Accuracy Rates Across Inattentional Blindness

A mixed ANOVA was run to assess any differences between group (IBs and NIBs) and image type (natural and violated) on accuracy of image categorisation, post-hoc power values were computed, and reported, for selected effects from SPSS. A main effect of image type was observed, with higher levels of accuracy seen in natural images (M = 81.17%, SD = 9.83) than in violated images (M = 71.14%, SD = 14.26), $F(1,21) = 5.89$, $p = 0.02$, $\eta_p^2 = 0.21$, power = 0.63 (see Figure 2.6). The interaction between image type and group was non-significant, $F(1,21) = 1.38$, $p = 0.25$, $\eta_p^2 = 0.06$, power = 0.20. The between subjects effect was also non-significant, $F(1,21) = 0.13$, $p = 0.72$, $\eta_p^2 = 0.01$, power = 0.06.

Reaction Times Across Inattentional Blindness

The same ANOVA was run for reaction times, with an approaching significant effect of image type observed, $F(1,21) = 3.51$, $p = 0.08$, $\eta_p^2 = 0.14$, power = 0.43 (see Figure 2.6), with faster reaction times in violated images (M = 2.24s, SD = 1.55), than in natural images (M = 2.45s, SD = 1.69). Again, the interaction between image type and group was non-significant, $F(1,21) = 1.20$, $p = 0.28$, $\eta_p^2 = 0.05$ power = 0.18, as was the between subjects effect, $F(1,21) = 0.82$, $p = 0.38$, $\eta_p^2 = 0.04$, power = 0.14.

Correlation of Accuracy with Image Error Rates

A correlation was run between the computed average error rates of each synthesised image and the average accuracy rate that the corresponding image received, with a significant negative correlation observed for accuracy, r(98) = -0.23, $p = 0.03$ (see Figure 2.6).

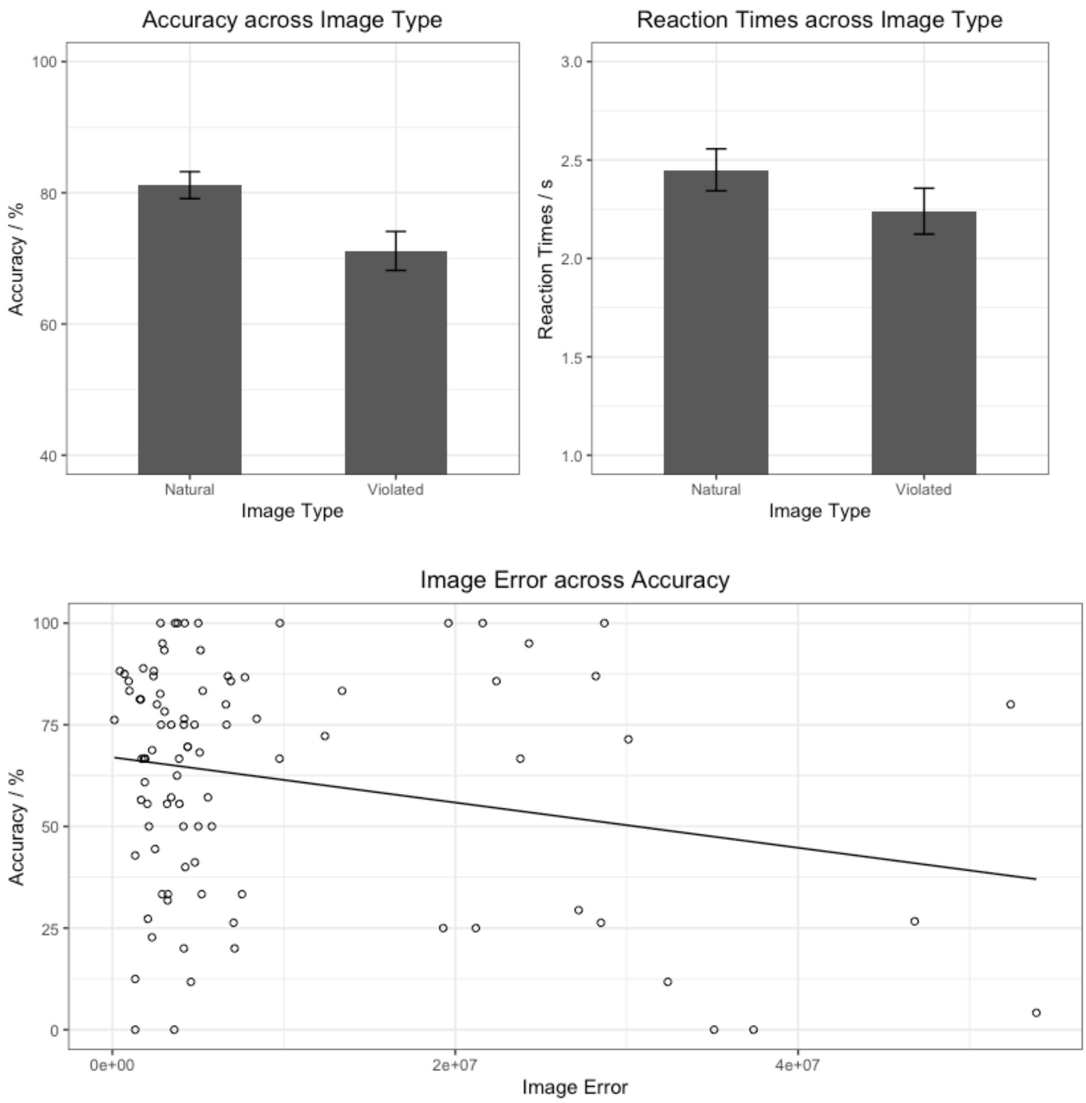


Figure 2.6. Top Left: Main effect image type on accuracy. Top Right: Main effect of image type on reaction times, bars denoting standard error of the mean for both. Bottom: Correlation between accuracy and averaged error recorded in the image synthesis process.

2.1.4 Discussion

It was hypothesised that participants that were classified as inattentional blind would show lower scores on the CBTT than those that are classified as non-inattentional blind. Furthermore, inattentional blindness participants will elicit lower accuracy scores on the image discrimination task, in addition to slower reaction times. The last two analyses did not carry any theoretical hypotheses as the median split was conducted in order to categorise images for Study 2.2, and the correlation was run to assess any relationship between the error term produced in image quilting and the accuracy rates per image.

In relation to the hypotheses stated, inattentional and non-inattentional blind participants did not differ in their CBTT scores, furthermore, inattentional blindness status did not predict differences in ability to categories images based on their nature, this was applicable to both accuracy rates and processing speed. There was however a main effect of image nature on accuracy rates, whereby higher accuracy rates were observed for natural images compared to artificial images. This finding can be explained through the variance of difficulty in the artificial images, whereby some images would be easier to categorise and others more difficult. These more difficult images may have then had more on an effect on accuracy, driving averages down. The median split did not have implications for any hypotheses, and whilst there seems to be a significant correlation between image error and accuracy rates, this does seem to be heavily affected by outliers that carry an extreme error value.

The lack of a significant difference between inattentional and non-inattentional blind participants in capacity scores does reflect research that has suggested it is a product of stochastic nature and not an internal propensity or trait. Research that has found no link between working memory capacity measures and inattentional blindness (Bredemeier & Simons, 2012; Kreitz et al., 2015, Beanland & Chan, 2016) have implicated experimental factors such as participant age range, primary task practice, and the salience of the unexpected stimulus. Although these studies all used the varying tests of working memory capacity and not the CBTT, the link is debated, and using the test of working memory capacity that carries a link in surrounding research (operation span tasks), as opposed to one that carries similarities to the inattentional blindness tracking paradigm is a step for future research in this thesis.

Significant differences in successfully identifying incongruencies across image sets has been shown in research previously, with various methods, such as pasting incongruent objects into images, with congruent images associated with greater accuracy (Remy et al., 2013; Mudrik et al., 2010; Mudrik et al., 2014; Truman & Mudrik, 2018), and with the placement of targets in unexpected areas increasing rates of misses (Beanland, Ke, & Byrne, 2015). Image synthesis research has also shown greater accuracy for real textures compared to synthetic images created through the Portilla-Simoncelli model (Balas & Conlin, 2015). Results here may suggest a similar pattern, however, given that the artificial images varied on a level of subjective difficulty (different from the image error term), the differences here may be down to a level of variance within the group of violated images as opposed to any beneficial processing bias for natural images.

The correlation between the image error rates and accuracy rates suggests that the greater the computed image error the lower the chance that participants would correctly categorise the image. Research investigating image saliency in a randomorph test as a function of inattentional blindness (Papera et al., 2014; Papera & Richards, 2016) found that inattentionally blind individuals require an increased level of image saliency to reach comparable standards to non-inattentionally blind individuals, but that the general trend being that greater saliency increased the probability that participants would detect its presence. This is concomitant with theories of attention where the first stage of processing is the computation of early visual features (Itti & Koch, 2001).

Interestingly, here the general trend across participants was that increased error reduced the chance of correct categorisation, however, closer inspection of the scatterplot does show a small subset of images with large amounts of image error that in turn may influence categorisation results. From inspecting the scatterplot, the vast majority of images fall below the first interval on the image error scale, and no trend across these points seems apparent. Therefore, the overall trend that suggested an increase in image error correlated with greater difficulty in categorisation does not carry very much evidence, especially when considering evidence that suggests greater saliency facilitates greater accuracy (Papera & Richards, 2014).

Whilst there was a level of control in the creation of the images, with the error tolerance level, this was a consistent parameter and was not altered per image. Therefore, the algorithm aimed to create images with the least amount of error possible, with the tolerance being the greatest amount of error permitted, hence the clustering of images that fall under the first interval of image error. Although this is not a confounding issue for the following study, it may be a point to consider if using image quilting as an approach in future studies. Previous research looking into differences across semantically congruent and incongruent images (Mudrik et al., 2010; Truman & Mudrik, 2018) have tested for salience through the Itti and Koch visual saliency model (2000). This allowed for images to be compared across orientation, intensity, and colour information, in addition to differences in chromaticity (Neumann & Gegenfurtner, 2006).

For the creation of stimuli used in this study, the level of saliency was not computed due to the algorithm computing a direct measure of error. Whilst research into semantic congruency aimed to create images by placing an object into an existing image, and then using comparative analysis to ensure saliency did not differ across the image (specifically across the borders of the inputted object, Mudrik et al., 2010; Truman & Mudrik, 2018), or by placing incongruent patches (Papera et al., 2014; Papera & Richards, 2016). Here the violated images were assigned a matrix which provided an outlay for the amount of error per image, which was seen as sufficient to assess any patterns with sensitivity. Study 2.2 will build upon results from the current study by using the median split to categorise images based on their accuracy rates. This will be in order to investigate whether inattentionally blindness status can predict the level of inhibitory control elicited by participants in a flanker task.

2.2 Inhibitory Differences across Inattentional Blindness in Real and Artificial Stimuli

2.2.1 Introduction

Research Question

The following study will use the accuracy scores from Study 2.1 to categorise the artificial stimuli into either high violation images; images that were easier to identify in Study 2.1, or low violation images; images that were more difficult to identify. Consequently, for Study 2.2 stimuli are categorised as either high violation, low violation, or natural (images that had not undergone the image quilting process). The aim of the current study was to investigate whether neural inhibition to real-world images is allocated based upon the semantic inconsistencies of the image. Furthermore, whether the successful allocation of inhibition can be predicted by the inattentional blindness nature of individuals.

The N2pc/P_D Component

In order to assess inhibition levels, measures of EEG amplitude in the N2 range were taken, more specifically, the N2pc (positive contralateral) component. The N2pc is a posterior negative component observed at ~175ms post-stimulus onset. It appears contralaterally to the participant's cued visual field and has been reported to be linked to spatial attention generally, and target enhancement and distractor inhibition more specifically. Early work has suggested that the component reflects a covert deployment of visual attention, one that is top-down and sensitive to task relevant features as opposed to the distractor (Eimer, 1996; Eimer, 1998).

While there is controversy as to precisely what the N2pc represents in spatial attention, there is a wealth of research suggesting that it represents top-down target enhancement. It appears to be sensitive to discriminative difficulty (Liu, Lin, Zhao, & Roberson, 2016), rapid allocation of attention to task-set matching objects (Grubert & Eimer, 2016), and a more general allocation of attention based on perceptual saliency (Zhao et al., 2011; Töllner, Zehetleitner, Gramann, & Müller, 2011), with mechanisms specific to target enhancement of features (Li, Liu, & Hu, 2017; Eimer & Kiss, 2010; Mazza, Turatto, & Caramazza, 2009).

Experiments by Hickey and colleagues (2009) ruled out sensory processing task demands and separated the N2pc into two sub-components: distractor positivity (P_D) and target negativity (N_T). Specifically, given that the P_D was observed contralateral to the distractor, it was suggested that it reflected neural mechanisms of suppression on the representation of the distractor, as opposed to a sheltering of the target representation, which was assigned to the N_T, as this component was found contralateral to the target. Consequently, the P_D component has been suggested to reflect the mechanism by which individuals' lower attentional priority of stimuli (Burra & Kerzel), and the prevention and termination of attention (Sawaki, Geng, & Luck, 2012). Differences in the amplitude of the P_D correspond to distractibility, in addition to being correlated to the speed of response made to a target (Gasper & McDonald, 2014; Sawaki et al., 2012).

Importantly for this thesis, the distractor positivity is observed when the contralateral amplitude (contralateral to distractor) is more positive than the ipsilateral amplitude, where consequently it is taken to reflect distractor inhibition (Burra & Kerzel, 2014; Hickey et al., 2009; Gasper & McDonald, 2014, Gasper et al., 2016). The amplitude has also been observed to be an index of visual working memory capacity, where low-capacity individuals exhibit a lower P_D amplitude and are consequently unable to prevent distractors from capturing attention (Gasper et al., 2016). P_D activation has also been observed in an oculomotor task, where increased amplitude has been associated when participants refrain from making a saccade to the stimulus (Weaver, van Zoest, & Hickey, 2017), thus strengthening the case for its representation of active suppression. Recently, Drew, Williams, Jones and Luria (2018) observed an increase in N2pc/N_T amplitude due to repetition with real world objects that was hypothesised to reflect an early neural correlate of recognition. The component therefore represents a viable tool to investigate inhibition to image categories in the following study.

It is important to note as the N2pc has been divided into subcomponents (N_T and P_D), in the following study the term N2pc will be used to refer to the latency period that is being investigated. As it may be the case that allocation of inhibition or attention is dependent on the between grouping factor (working memory capacity).

Automated Operation Span Task

In the current study the task for indexing working memory capacity was changed from the block tapping task used in Study 2.1 (CBTT), to the automated operation span task (AOSPAN). The reason for this change was the established literature associating the AOSPAN to inattentional blindness, compared to the CBTT, even though the latter is a spatial span task and may carry more similarities to the nature of the inattentional blindness screening paradigm itself. However, a number of studies have used AOSPAN scores to predict the inattentional blindness nature of participants (Hannon & Richards, 2010; Richards, Hannon, & Derakshan, 2010; Papera & Richards, 2016; Papera & Richards, 2017), in line with a limited-resource hypothesis of inattentional blindness (Papera & Richards, 2016; Hannon & Richards, 2010), where individuals with lower levels of working memory capacity do not possess the capacity to process the unexpected change and therefore do not consciously perceive it.

The AOSPAN is the automated version of the operation span task (OPSAN: Turner & Engle, 1989), and has been associated with core cognitive functioning tasks, such as fluid intelligence (Colom, Abad, Quiroga, Suhih, & Flores-Mendoza, 2008; Engle, Tuholski, Laughlin, & Conway, 1999) and executive functioning (McCabe, Roediger, McDaniel, Balota, & Hambrick, 2010). Additionally, scores are seen to decline in line with disorders such as ADHD (Holmes et al., 2014), aging (McNab et al., 2015), and Alzheimer's (Stopford, Thompson, Neary, Richardson, & Snowden, 2012). Although a low correlation has been noted between the original OSPAN and the automated version, this has been mainly been put down to the presentation of the secondary task - with the original using whole words and the latter using single letters.

What is important to note is the same pattern of correlations that the two tests show with other tasks (Unsworth et al., 2005; Bollen, 1989). Furthermore, the automated version has been shown to load the same factors as the original OSPAN task in a factor analysis (Unsworth et al., 2005). The AOSPAN task falls under a family of span tasks, where participants have a serial recall with a distractor activity, whether it be reading (Daneman & Carpenter, 1980), counting (Case, Kurland, & Goldberg, 1982), or spatial judgments on mirrored objects (Shah & Miyake, 1996), with all showing good reliability (Conway, Cowan, Bunting, Therriault, & Minkoff, 2002), specifically the AOSPAN (Unsworth et al., 2005).

Given the established link between inattentional blindness and the AOSPAN, and the underlying low resource theory of inattentional blindness (Hannon & Richards, 2010; Papera & Richards, 2016), the AOSPAN was a stronger candidate for investigating whether capacity differences can predict the incidence of inattentional blindness. Furthermore, very strong correlations have been established between capacity scores from span tasks and executive functioning constructs (McCabe et al., 2010), with suggestions of an underlying executive attentional component. Of importance is the suggestion that complex span tasks, such as the AOSPAN, index abilities such as the focus of attention (Cowan et al., 2005), goal maintenance (Braver et al., 2007), and inhibitory control (Hasher et al., 2007). With performance in the inattentional blindness screening task relying on functions such as goal maintenance and inhibition, the AOSPAN was seen as a more valid measure to test the link between capacity and inattentional blindness.

Rationale

The rationale of the following study was to investigate whether the incidence of inattentional blindness can predict the ability to efficiently inhibit distractors that contain semantic inconsistencies. Whilst work had been done on saliency in texton displays (Papera et al., 2014), work here aimed to investigate potential differences in more natural displays, given that original inattentional blindness research and implications for the phenomenon have strong associations with the natural world. The rationale for the flanker paradigm was to measure the amplitude in the N2pc range, which as a contralateral component, required stimuli to be placed laterally. The indexing of the P_D was done in order to measure the allocation of inhibition, a mechanism linked to inattentional blindness. It would be hypothesised that the contralateral amplitude to the distractor would therefore be more positive than the ipsilateral amplitude.

Although the main emphasis of the study was on the allocation of attention in the N2pc range, amplitudes were also investigated in the N1 range. Previous inattentional blindness research has shown differences of deployment of resources in the N1 range (Papara & Richards, 2016), where lower amplitudes are linked to inattentional blindness, to both high and low salient images. The N1 was also found to be sensitive to manipulation of texture synthesis and polarity reversal in an image comparison task (Balas & Conlin, 2015). Lastly, the central task within the flanker paradigm was taken from Shafto and Pitts (2015), which was used to investigate inattentional blindness in a face processing paradigm and was therefore seen as congruent with the aims of the study.

Hypotheses

Firstly, in line with the resource-based hypothesis of inattentional blindness, it is hypothesised that individuals with inattentional blindness will score significantly lower on the AOSPAN than those that are classified as non-inattentionally blind. Secondly, inattentionally blind participants, due to their lack of resources, will not be able to inhibit distractors based on categories, meaning the same level of inhibition will be allocated to all distractors. This will differ from non-inattentionally blind participants, who should be able to allocate more inhibition for the high violated images compared to natural and low violation images, due to the surplus of resources. It is important to note as the N2pc has been divided into subcomponents (N_T and P_D), in the following sections the term N2pc will be used to refer to the latency period that is being investigated. As it may be the case that allocation of inhibition or attention is dependent on the between group factor.

2.2.2 Methods

Participants

A total of 25 participants were recruited using a cloud-based participant management software. All had normal or corrected to normal vision and were naïve to the experimental hypotheses. All experimental procedures were approved by the Birkbeck research ethics committee, and informed consent was taken before testing. Participants were excluded through ambiguous answers to inattentional blindness probes (one participant excluded), less than 50% accuracy of hits on the inattentional blindness screening task (no participants excluded), no observation of the change in the full attention inattentional blindness trial (no participants excluded), not reaching the reaction time threshold on the AOSPAN (no participants excluded), or a trial rejection rate of 40% or higher from EEG pre-processing (eight participants excluded). The remaining 16 participants were aged between 20 – 41 (M = 33, SD = 10.5).

Flanker Task – Stimuli

The stimuli for the flanker task were created on Matlab (Mathworks) and the Psychtoolbox extension (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007), the monitor used was a Samsung SyncMaster 2233, with display measurements of 1920 x 1080, with a viewing distance of 60cm. The flanker task had two components; the central task within the flanker was taken from Shafto and Pitts (2015). Here the central dot task consisted of three concentric circle outlines with radii that subtended to 0.69°, 1.38° and 2.07° around a fixation cross of 0.41 x 0.41°. On each circle was a black dot, 0.27°, which randomly moved to different positions on the circle. The central stimuli were then flanked by two opposing rectangles 4.3° away from the central fixation cross, with each rectangle subtending to 7.7 x 5.5°. The images from Study 2.1 were grouped into the following categories: 50 random natural images, 50 high violation images (from median accuracy and above), and 50 low violation images (from median accuracy and below).

Flanker Task - Procedure

Participants completed the flanker paradigm first and began with a practice session that consisted of 10 trials, that were identical to the main experiment trials. A single trial would contain four parts (see Figure 2.7 for trial sequence): part one showed the fixation cross, the three circle outlines that surround the fixation cross, and the two flanker rectangles (100ms). Part two: the same display was presented but with a dot presented at a random location at each of the three circle outlines (500ms). Part three: the screen after again presented the same display, but with the location of the three dots re-randomised and with a distractor image in one of the flanker rectangles (500ms), this screen would be shown after a variable trial interval, between 500-2000ms. Part four: the trial would finish with showing participants the dots in a re-randomised location again, with the same stimuli as part two (500ms).

On 5% of trials one of the dots (placed on the circle outlines) would temporarily turn yellow (for 500ms), and the task consisted of 10 blocks of 50 trials. For five consecutive blocks, participants were instructed that they must fixate on the central fixation cross but to press the spacebar whenever they noticed a yellow dot.

For the other five consecutive blocks, participants were instructed to fixate on the central fixation cross but to press the spacebar whenever they noticed a yellow dot, and when this yellow dot was grouped along with the other two dots in the left or right half of the screen. This manipulation of load was counterbalanced across participants. Participants were also informed that distractors would be present within a trial, but to ignore them as best they could, and to focus on the central task.

Flanker Task - Factors

The independent variables in the flanker task were the distractor type; either high violation, low violation or natural, and task load, where participants had to monitor just a colour change of the dots, or increased load where participants had to monitor a colour change and the position of all dots. EEG was recorded throughout the task and inhibition was investigated through the N2pc time window.

Flanker Task - Relevance

The function of the flanker task was to examine whether levels of inattentional blindness could predict the ability to vary inhibition based on semantic inconsistencies in real-world textures. The flanker design is congruent with the contralateral nature of the N2pc component, where a distractor image is placed laterally to the central task, and N2pc amplitude can then be measured contralaterally. The type of distractor image was manipulated in order to investigate whether the capacity differences that drive inattentional blindness result in higher capacity individuals being able to inhibit distractor images based on their category due to their greater resources, and whether low-capacity individuals fail to inhibit based on category. A failure for low-capacity participants to inhibit based on category would then be a product of fewer available resources and would be congruent with research linking inattentional blindness to low working memory capacity and with a lack of sensitivity to low-level saliency (Papera et al., 2014; Papera & Richards, 2016).

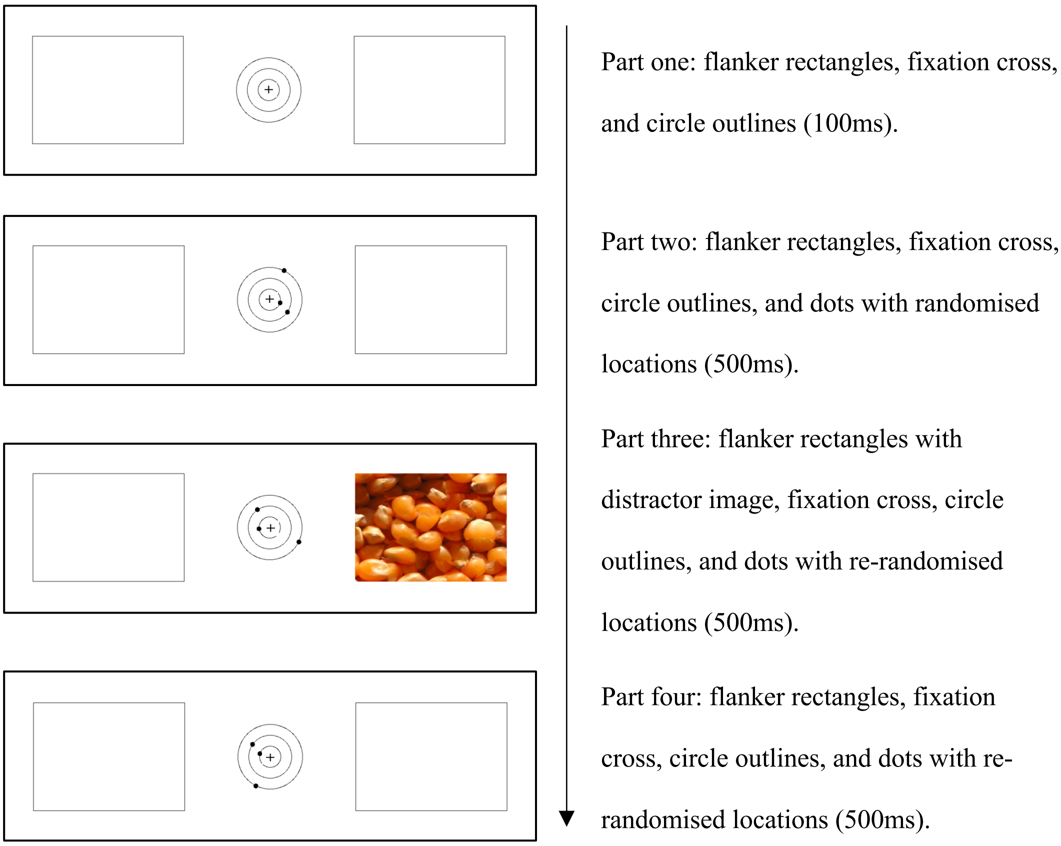


Figure 2.7. Trial sequence for the Flanker Task.

Flanker Task - EEG Recording and Analysis

EEG was recorded with silver electrodes mounted on an elastic cap (Easy-Cap) from 28 electrode positions (FPz, FP1, FP2, Fz, F3, F4, F7, F8, FCz, FC1, FC2, FC5, FC6, Cz, C3, C4, Cz, CP1, CP2, CP5, CP6, Pz, P3, P4, P7, P8, O1, O2), according to the International 10-20 system. Horizontal EOG was recorded bipolarly from the outer canthi of both eyes. Electrical impedances were kept below 5 kΩ, with the impedances of the earlobe electrodes as equal as possible. The bandpass was 0.01 – 40 Hz and sampled at 500 Hz using a SynAmps amplifier (NeuroScan). Trials with saccades (HEOG exceeding ±25 μV), eye blinks (FP1 and FP2 ±60 μV), or movement artefacts (±100 μV at all other electrodes) were discarded from the analysis. The continuous EEG during the stimuli presentation was epoched into 500ms windows, time-locked to the beginning of the presentation of the distractor stimulus screen (Figure 2.7 part three), with a baseline corrected period of 100ms.

In order to compute the contralateral amplitudes, activity was averaged from the O1, P7, and P3 electrodes (left cluster) and the O2, P4, and P8 electrodes (right cluster). These clusters were then used to compute difference waves by subtracting the response for the ipsilateral hemisphere from the contralateral hemisphere for the respective lateralised trials. For instance, if the distractor image appeared to the right, the activity from the right cluster would be subtracted from the left to compute the difference amplitude. These difference waves were then averaged across for trials where the distractor image appeared to either the right or left.

Time windows were identified by a two-step process, firstly, datasets were averaged across all participants and difference waves were plotted for high violation, low violation, and natural stimuli. Peak latencies were then calculated through the peak latency option in EPRLAB (Lopez-Calderon & Luck, 2014), which provides the latency of the highest (either positive or negative) peak within a selected time window. These time windows were isolated through both previous literature of the N1 and N2 ranges and through observation of the plotted grand averaged waveforms. The resultant three latencies for each stimulus category (high violation, low violation, natural) were then averaged across to provide one peak latency for both the N1 and N2 range. Final time windows were then calculated by using a 50ms range on either side of the peak: N1 (132ms-232ms) and N2pc (246ms-346ms). Statistical tests were completed using the Statistical Package for the Social Sciences (SPSS) 23.0, with a specialist ERP toolbox (Lopez-Calderon & Luck, 2014) for the EEGLAB software (Delorme & Makeig, 2004) used for processing of the EEG data.

AOSPAN Task - Stimuli

The AOSPAN task was run on PEBL software (Meuller & Piper, 2014), the monitor used was a Samsung SyncMaster 2233, with display measurements of 1920 x 1080, with a viewing distance of 60cm. Stimuli all appeared centrally within an area of 8 x 8°, and were consistently coloured white on a black background. The order of letter sequence length was randomised for each participant.

AOSPAN Task – Procedure

The AOSPAN task was completed second, was based on the original operation span task (Tuner & Engle, 1989). The task began with a practice session of three parts, in the first part of the practice, participants were presented with letter sequences, with each letter presented on screen for 800ms. The sequence length ranged from two to seven letters and participants were instructed to remember the sequence. Participants were then prompted to recall the letter sequence by clicking on the correct letters in sequence from a 4 x 3 grid of letters presented on screen. Participants completed four trials of the first part of the practice. In the second part of the practice session, participants were presented with mathematical equations to the template '(x +/- y) +/- z =?', which had to be mentally solved as quickly as possible, with the pressing of the left mouse key to indicate completion. Once the left mouse key had been pressed an answer was then presented on screen and participants had to click either 'true' or 'false' depending on their calculation.

In this part of the practice the mean time taken to answer was calculated in order to account for individual differences in ability, thus, 2.5 standard deviations above this mean was set as the threshold for the time limit, this restricted the chance of letter sequence rehearsal. Participants completed 20 trials in this second part of the practice. The last part of the practice session combined both the letter sequencing and mathematical equations and was identical to the main experimental trials, participants completed two trials of the last part of the practice. The main experimental trials began with a mathematical equation in the format identical to the practice session shown for the time limit calculated in practice session two, and once participants had answered the true or false probe, a single letter was flashed for 800ms.

Letter sequences within a trial (number of letters shown) could vary from two to seven, with a mathematical equation shown before each, and after a trial was complete participants were shown the 4 x 3 letter grid and had to enter the letters in the sequence that they appeared. A total of 17 trials were shown to each participant, each sequence length was shown three times (apart from the two letter sequences that were only shown twice) in a randomised order. Participants were instructed to not prioritise one task over the other (see Figure 2.8 for trial sequence).

AOSPAN Task – Factors

AOSPAN scores were computed for each participant, which were the sum of all correctly recalled trial lengths. If a participant incorrectly recalled even just the one letter, for instance recalling six correct letters in a seven-letter trial, the length was still excluded.

AOSPAN Task - Relevance

A number of studies have used AOSPAN scores to predict the inattentional blindness nature of participants (Hannon & Richards, 2010; Richards et al., 2010; Papera & Richards, 2016; Papera & Richards, 2017), in line with a limited-resource hypothesis of inattentional blindness (Papera & Richards, 2016; Hannon & Richards, 2010), where individuals with lower levels of working memory capacity do not possess the capacity to process the unexpected change and therefore do not consciously perceive it. More specifically, the task has been used to predict inattentional blindness nature in experiments that also associate inattentional blindness to sensitivity in varying levels of low-level saliency (Papera et al., 2014), and divergent neural patterns in attentional control (Papera & Richards, 2017).

Inattentional Blindness Screening Task - Stimuli and Procedure

The inattentional blindness screening task was identical to the task used in Study 2.1.

Inattentional Blindness Screening Task - Factors and Relevance

The task and relevance for the inattentional blindness screening task was identical to the task used in Study 2.1.

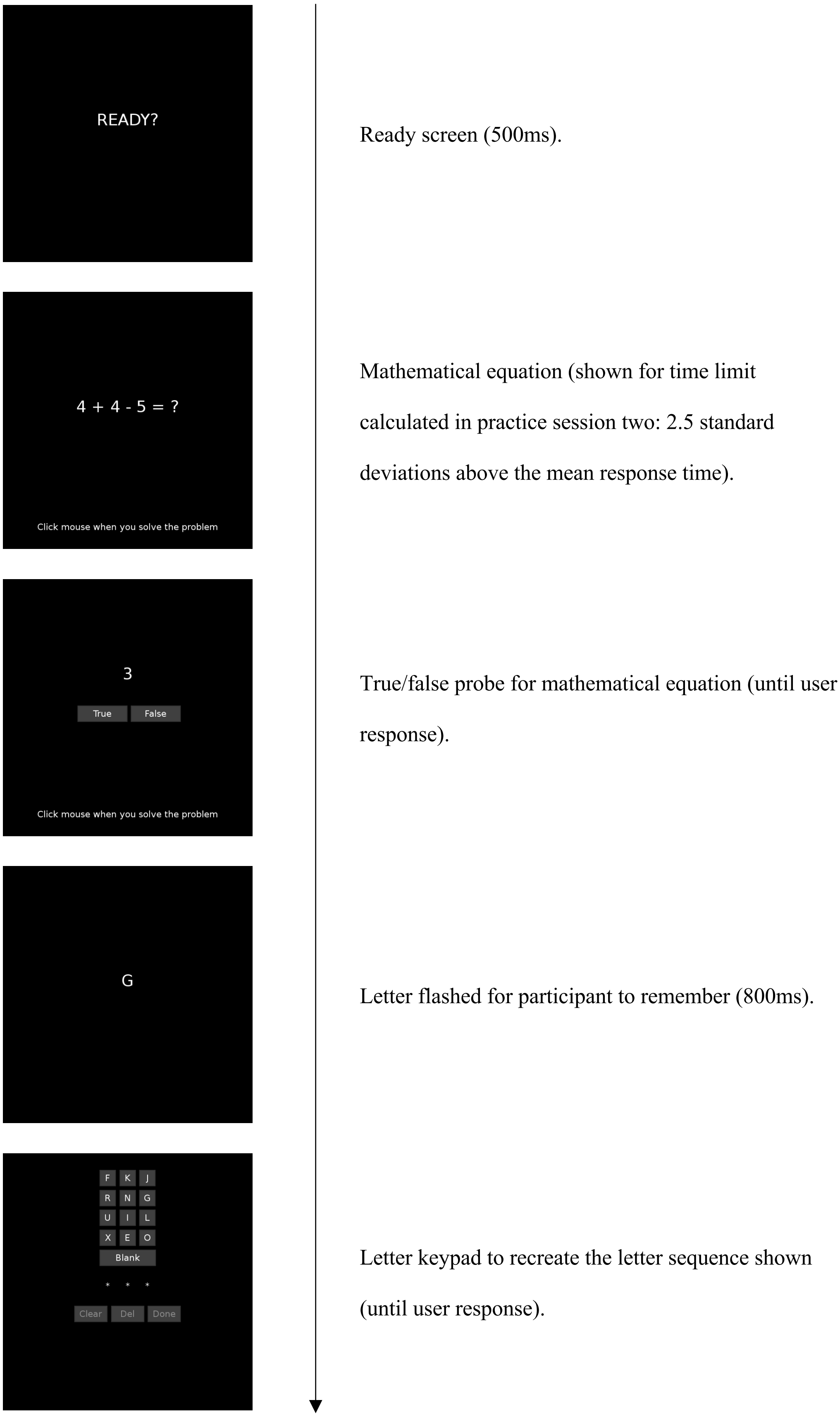


Figure 2.8. Example trial sequence of the AOSPAN, for a single letter sequence.

2.2.3 Results

Capacity Differences Across Inattentional Blindness

An independent t-test was run across the two groups (inattentionally blind/IB participants = 10, non-inattentionally blind/NIB participants = 6) and AOSPAN scores to investigate differences in capacity across inattentional blindness groups. Post hoc power values were computed using G*Power (Faul et al., 2007). No significant difference was observed across groups: IBs (M = 43.60, SD = 19.05) and NIBs (M = 45.20, SD = 27.10), $t(15) = -0.15$, $p = 0.89$, $d = -0.86$, power = 0.10.

N1 (132ms-232ms)

Before testing for differences across inattentional blindness group, testing for the strength of the component was conducted through a within subject ANOVA, with contralaterality (contralateral and ipsilateral), load (low and high), and image type (high, low, and natural) as within subject factors. Bonferroni corrected comparisons were then used to assess significance between contralateral and ipsilateral waves for each condition. A main effect of contralaterality was observed, $F(1,15) = 40.87$, $p < 0.01$, $\eta_p^2 = 0.73$, although no three way interaction with load, image type, and contralaterality was present, $F(2,30) = 0.14$, $p = 0.86$, $\eta_p^2 = 0.01$ (see Table 2.1 for comparisons).

Using the time windows identified through maximal peaks in grand averaged waveforms, mean amplitudes were taken from the N1 range and compiled into a mixed ANOVA, with load and image type as within subject variables, and inattentional blindness status as the grouping factor. The main effect of image type, main effect of load, and all interactions did not show significance, F's < 0.21 and p's

> 0.13. The between subject factor also did not show significance, $F(1,14) = 0.11$, $p = 0.74$, $\eta_p^2 = 0.01$, with a near identical mean amplitude for IBs (M = 1.63μV, SD = 1.04) and NIBs (M = 1.82μV, SD = 1.20, see Figure 2.9 for waveforms averaged across all participants for image type).

Table 2.1. Bonferroni Comparisons for laterality for each condition within N1 window.

Target Load	*Image Type*	*Contralateral / μV*	*Ipsilateral / μV*	*t value*	*p value*
High	High Violation	-0.21	-1.93	5.55	< 0.01
High	Low Violation	-0.49	-1.95	4.70	< 0.01
High	Natural	-0.35	-2.07	5.54	< 0.01
Low	High Violation	0.42	-1.36	5.78	< 0.01
Low	Low Violation	0.19	-1.37	5.05	0.02
Low	Natural	-0.13	-2.08	6.30	< 0.01

N2pc (246ms-346ms)

Statistical significance was for the N2pc time window was tested in the same manner as previously, with mean amplitudes for contralateral and ipsilateral waves taken for each participant and compared in an ANOVA across conditions. A main effect of contralaterality was observed, $F(1,15) = 37.37$, $p < 0.01$, $\eta_p^2 = 0.71$, in addition to an image type by contralaterality interaction, $F(2,30) = 3.28$, $p = 0.05$, $\eta_p^2 = 0.17$, but no three-way interaction $F(2,30) = 1.48$, $p = 0.24$, $\eta_p^2 = 0.09$ (see Table 2.2 for comparisons).

An ANOVA was run in the N2pc latency range with the identical parameters as previously, with selected post hoc power values reported from SPSS. An approaching significant main effect of image type was observed $F(2,28) = 2.69$, $p = 0.08$, $\eta_p^2 = 0.16$, power = 0.49, with a N2pc amplitude for high violation images (M = 2.24μV, SD = 1.33) approaching a significantly greater difference compared to natural images (M = 1.83μV, SD = 1.56), $p = 0.06$ Bonferroni corrected. Neither category significantly differed from low violation images (M = 1.94μV, SD = 1.30), all p's > 0.31. The main effect of load and all interactions were non-significant, F's < 1.54, p's > 0.23. The between subject factor of inattentional blindness also did not show significance, $F(1,14) = 0.67$, $p = 0.42$, $\eta_p^2 = 0.04$, with a slightly greater mean amplitude for IBs (M = 2.28μV, SD = 1.46) than for NIBs (M = 1.70μV, SD = 1.19, see Figure 2.10 for waveforms averaged across inattentional blindness group).

Table 2.2. Bonferroni Comparisons for laterality for each condition within N2pc window.

Target Load	*Image Type*	*Contralateral / μV*	*Ipsilateral / μV*	*t value*	*p value*
High	High Violation	2.38	0.02	6.15	< 0.01
High	Low Violation	2.27	0.41	4.81	< 0.01
High	Natural	1.96	0.36	4.19	0.02
Low	High Violation	3.34	1.10	5.99	< 0.01
Low	Low Violation	3.27	1.07	5.74	< 0.01
Low	Natural	2.69	0.53	5.65	< 0.01

Figure 2.9. Top Left: Contralateral (black), ipsilateral (grey), and difference (coloured) waves plotted, averaged across all participants for high violation images, negative is plotted up on the y axis. Waveforms are averaged from clusters specified in *Flanker Task - EEG Recording and Analysis,* and 0ms represents the onset of the distractor stimuli screen (Figure 2.7 part three). Top Right: The same but for low violation images. Bottom Left: The same but for natural images. Bottom Right: Difference waves plotted for all image types, averaged across all participants. Colour schemes remain consistent, negative is plotted upwards, and dotted vertical lines represent component latencies.

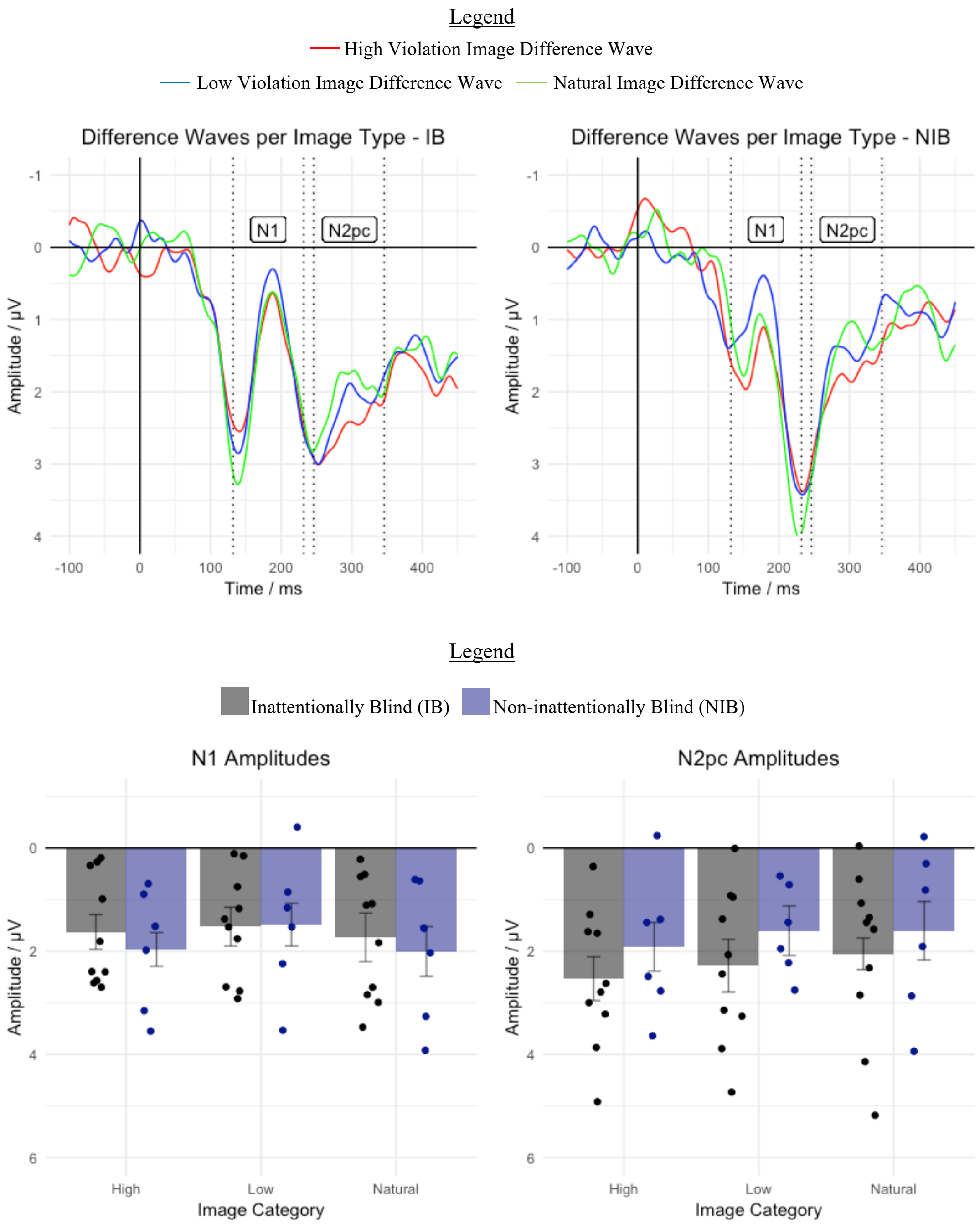


Figure 2.10. Top Left: Difference waves plotted for all image types, averaged across inattentionally blind participants. Waveforms are averaged from clusters specified in *Flanker Task - EEG Recording and Analysis,* and 0ms represents the onset of the distractor stimuli screen (Figure 2.7 part three). Negative is plotted upwards, and dotted vertical lines represent component latencies. Top Right: The same but for non-inattentionally blind participants. Bottom Left: Mean amplitudes across inattentional blindness group in the N1 range, negative is plotted up, bars denote standard error of the mean, with plotted individual datapoints. Bottom Right: The same but for the N2 range.

2.2.4 Discussion

In summary, Study 2.2 investigated whether differences in inattentional blindness categorisation could firstly predict working memory capacity, in line with the resource-based hypothesis of inattentional blindness (Hannon & Richards, 2010; Richards et al., 2010; Richards et al., 2012; Richards et al., 2014; Papera & Richards, 2016; Seegmiller et al., 2011), and secondly whether inattentional blindness category could predict the allocation of inhibition based on semantically violated images. Despite using a more established measure of working memory capacity (AOSPAN) compared to Study 2.1, no differences were found across inattentional blindness group. Furthermore, across the two component latencies identified, N1 and N2pc, only a main effect of image type was observed in the latter. This main effect of image type in the N2pc latency range reflected an increased amplitude (more relative negative N2pc) for natural images compared to high violation images. No between subject effects or group-based interactions were found across inattentional blindness in either component latency, despite differing waveforms.

Results therefore do not sit congruently with hypotheses, the first of these: that inattentional blindness categorisation should predict differences in working memory capacity was a hypothesis in a research area that contains two strong opposing sides. The lack of significant difference across capacity scores is therefore reflective of research that argues inattentional blindness is a stochastic phenomenon, as opposed to participant-based trait. There are however a number of points to be considered on this lack of effect. The first of these is the dual-route theory of inattentional blindness (Richards et al., 2014), whereby participants that score highly in capacity measure tests still elicit inattentional blindness due to the processing and consequent inhibition of the ‘missed’ stimulus. The control of this potential confound was attempted, through making the unexpected change in the inattentional blindness paradigm one that involves the targets, as opposed to an unexpected red cross as with previous forms of the test. However, it is possible that this unexpected change was processed and inhibited by higher working memory capacity individuals, thus classifying them as inattentionally blind. This would then consequently equalise the capacity scores across groups, resulting in a lack of effect.

The second point to be considered in regard to the lack of effect across working memory capacity scores is the nature of the inattentional blindness screening task. While the screening task has been used previously to categorise participants, and then consequently to successfully predict differences in electrical and behavioural data, the one trial nature of the paradigm does mean that retest reliability is unavailable. This has considerable implications for the field, as associating working memory capacity scores to inattentional blindness tendency cannot occur multiple times in single participant. This ultimately weakens the link between working memory capacity and inattentional blindness, and the possibility of observing an association between the two in the current study. The last factor to consider for this main effect is the unequal groups and overall small sample size. Although previous research has observed results using similar sample sizes (IBs/NIBs = 14/7, Papera & Richards, 2014; IBs/NIBs = 7/12, Papera & Richards, 2017), increased the power would have helped to isolate whether a difference in this case was present.

Although differences in the N1 range across inattentional blindness groups has been documented (Papera & Richards, 2016), when absolute differences have been compared between groups, comparative performance has been found (Papera & Richards, 2016). It is therefore not surprising that no effect in the N1 range has been observed in the current study. Furthermore, when considered with research that has shown a N1 enhancement for stimulus discrimination (Mangun & Hillyard, 1991), as opposed to such an enhancement when stimuli are placed as lateralised distractor, it may be the case that the paradigm was not one that facilitates early amplification in the N1 range. However, the flanker paradigm was specifically used to discern differences in distractor inhibition across inattentional blindness. Here participants exhibited a greater negative amplitude for natural images compared to high violation images.

This finding can be taken one of two ways: firstly, covert attention was captured significantly more so by natural images than by highly violated images. This would rely on the logic that it is not inhibition that is driving the difference, specifically inhibition of more salient stimuli. Instead, natural images attract covert attention more so than images that carry large contextual violations. Secondly, evidence has linked the P_D in the same latency window to the N2pc, and even earlier when the paradigm requires quick distractor suppression (Kerzel et al., 2018), with a sequential effect following paradigms that encourage suppression after enhancement, such as with more demanding search tasks (Feldmann-Wüstefeld & Schubö, 2013). The relationship between the N2pc and the P_D seems to be very much dependent on the efficiency of the visual search, with efficient parallel search solely eliciting a P_D (Feldmann-Wüstefeld & Schubö, 2013), and involuntary attentional capture in slow exposure trials eliciting a N2pc (Gasper & McDonald, 2014).

Furthermore, given that contralateral amplitudes were more positive compared to ipsilateral amplitudes across conditions, it would suggest that the distractor encouraged inhibition, rather than the allocation of attention. As this is seen with the recording of P_D (Burra & Kerzel, 2014; Hickey et al., 2009; Gasper &

McDonald, 2014, Gasper et al., 2016). With evidence regarding distractor suppression and variance in the latency of the component, it may be the case that the difference in mean amplitudes between high violation and natural images represent distractor positivity instead of target enhancement. This is to say that the lack of attention to a distractor, such as the high violation image, represents increased inhibition, as naturally the more violated image should demand the same level, if not more, attentional resources. The results are then much more in-line with previous research, with the results here suggesting greater covert inhibition is required for images with a large degree of violations compared to unaltered images. This is further suggestive when looking at the means between groups, with non-inattentionally blind participants showing a consistent pattern of greater inhibition across each image type compared to inattentionally blind participants, albeit with no significant interaction terms.

This is similar to research into neural differences across inattentional blindness, with capacity scores in the CDA range predicting the level of inattention (Papera & Richards, 2017): specifically, non-inattentionally blind participants being superior at maintaining representations under higher loads. More poignantly, a prefrontal bias reflecting active suppression (Liesefeld et al., 2014) has also been shown to vary across inattentional blindness (Papera & Richards, 2017), with non-inattentionally blind individuals orientating resources more efficiently to the suppression of distractors. This would fit well with the pattern of means in this study, and the lack of significance across groups may be due to the power issue: where in this particular case, further participants are required to substantiate concrete conclusions.

2.3 General Discussion

The two studies presented in this chapter had two broad overarching aims: firstly, to replicate a number of studies in the inattentional blindness literature that supports the resource-based hypothesis of the phenomenon, by isolating differences in working memory capacity. The second aim was to investigate whether inattentional blindness categorisation could predict the ability to allocate attention based on the semantic saliency of distractor images. These images were categorised based on the results of Study 2.1, and then used as distractors in Study 2.2 in order to measure mean amplitudes in the N2pc time window. It was argued that the use of image quilting to create the semantic saliency in these distractor images would help to replicate results that have been observed across inattentional blindness groups in low level search displays, but with stimuli that replicated our everyday visual experiences.

Results however failed to observe any differences across inattentional blindness group, this covered both the working memory capacity scores, and for amplitudes of inhibition in Study 2.2. However, participants in general did elicit a greater (more negative) amplitude for natural images compared to high violation images. This difference in amplitude was considered as both an increased enhancement, with greater enhancement for natural images, or as an increased inhibition, with greater inhibition for high violation images. The latter conclusion was emphasised, it was argued that given research has shown inhibition can occur in the same latency period as target enhancement but with efficient visual search (Feldmann-Wüstefeld & Schubö, 2013), differences may reflect an inhibitory difference. This was strengthened by the more positive contralateral waves to the distractor compared to the ipsilateral waves. Results therefore have a number of implications, that will be discussed in the following sections.

Image Quilting as an Experimental Tool

One of the methodological implications that this chapter carries concerns the image quilting process used to create the distractor stimuli. The section will discuss a number of potential improvements to the method, however, ultimately, results from Study 2.2 strongly suggest that image quilting can be used to investigate differences to real-world textures. One of the improvements concerns the minimum error boundary cut, which attempts to minimise the computational cost of the cutting procedure along the path of two blocks. This occasionally leads to a shortcut in computational cost to avoid the cut having to travel a longer distance to keep discontinuities to a minimum. An example of a solution of this is in the work of Long and Mould (2007), where the number of paths that can be taken by the boundary cut are stored in decreasing order of cost. This is then implemented by comparing prospective paths, and then choosing the path which minimises the maximum edge costs of the pathway. An investment into reducing the computational cost of this would be required before it can be implemented.

Another potential improvement could be to address the process of block selection, where in the algorithm used in this chapter a random block was selected from a group of matches as opposed to selecting the optimal block to reduce error (O'Brien, Wickramanayake, Edirisinghe, & Bez, 2004). The reason for the random selection was to avoid confounding factors such as repetition. However, a trade-off between such repetition and a greater emphasis on the optimal block should be considered if such a technique will be used in the future. Although the image quilting method provided a procedure to help assess sensitivity to contextual violations, a limiting factor was the lack of control in moderating the size and spread of violations. Research that has similarly investigated differences in congruency in low-level settings have used a more systematic approach to manipulating salience (Papera et al., 2014; Feldmann-Wüstefeld et al., 2017). In addition to focusing on maintaining low level statistics such as position, orientation, and scale (Balas & Conlin, 2015).

One further improvement to the image quilting process would be that of selective implementation, whereby the process is used to quilt a gap in the image, instead of producing a new image. Stimuli produced in this method would then meet a criterion mentioned in this section; increased control, although it may be at a cost of computational power and time. Despite the increased demands, using such a technique would allow investigations to incorporate more visual search paradigms, thus allowing research to mirror existing inattentional blindness and low-level search literature (Papera et al., 2014; Papera & Richards, 2016). Therefore, in the next chapter a new approach will be introduced to create more systematic violations in image textures. This method will be used in conjunction with the neural indexes used in this chapter to investigate whether sensitivity differences emerge across working memory capacity.

Implications for Inattentional Blindness

Implications for inattentional blindness are twofold, as throughout this chapter inattentional blindness was investigated in regard to working memory capacity differences and the differing allocation of inhibition. For both Study 2.1 and 2.2 no significant difference in working memory capacity scores were observed across inattentional blindness groups, this covered both the CBTT (Study 2.1) and the AOSPAN (Study 2.2). Results therefore suggest that inattentional blindness does not carry a relationship to working memory capacity (see Beanland & Chan, 2016), in spite of evidence for the contrary (Hannon & Richards, 2010; Richards et al., 2010). However, one theory that does require acknowledgement, and may have influenced results in the current chapter, is the dual-route theory of inattentional blindness (Richards et al., 2014).

Original data from the Richards study (2014) suggested that individuals with higher working memory capacity individuals elicited a better use of strategy that was dependent on the circumstances. When the change was goal-relevant such individuals were better at noticing, and similarly better at inhibiting the change when it was goal-irrelevant. Whilst the inattentional blindness screening task used in this chapter included a task-relevant change (see also Papera & Richards, 2017), the fact that the change still distracted from the primary goal of observing target hits could mean that it was inhibited by high working memory capacity individuals and consequently not seen. This notion of variable inattentional blindness results within the higher working memory capacity cohort is supported by research showing that individuals with higher working memory capacity show greater flexibility in strategy use under load (Vogel et al., 2005), and flexible allocation in a selective attention task (Bleckley, Durso, Crutchfield, Engle, & Khanna, 2003).

This idea that high working memory capacity participants might have a surplus of resources which may be employed in increased suppression of information has been proposed by a number of theories. For instance, the inhibition view, which proposes that high working memory capacity individuals would be less distracted by visual stimuli due to superior inhibitory capacity (Hasher, Lustig, & Zacks, 2007). In addition, the focus of attention view, where an increased ability to constrain attention results in a smaller propensity for distraction (Heitz & Engle, 2007). The points raised indicate that if inattentional blindness represents a cognitive trait as opposed to an emergent phenomenon due to experimental parameters, the classification may still carry ambiguity for those that have a higher working memory capacity. Due to this level of uncertainty, in the following chapter more of an emphasis will be placed on the individual differences across levels of working memory capacity, rather than categorising individuals on the basis of a one trial phenomenon.

Top-down Influences in Attention

Results from the chapter also carry implications for top-down influence in attentional, specifically the variable amplitude found in the N2pc range to image type in Study 2.2. This is the first reported occasion of such amplitude being dependent on the presence of violations in such complex scenes in a flanker paradigm. This finding therefore has implications for classic attention theories which state that visual processing should be far more efficient in simple, low-level scenes compared to stimuli that emulate complex ones. Although the exact nature of the variance in the N2pc range was debatable, research has suggested that a more positive-going deflection is representative of inhibition, when visual search is efficient (Feldmann-Wüstefeld & Schubö, 2013). One process that was not a priori investigated in the timeline of prior object categorisation is a frontal ERP effect which has been shown to precede spatial object processing (Thorpe, Fize, & Marlot, 1996). The presence of this frontal component would add further evidence to the notion that the inhibition shown by participants was indexed after a level of categorisation and was not a reaction to low-level image statistic differences.

Results in this chapter also have general implications for the level of cognitive penetrability in attention. From a later, behavioural perspective, scenes and objects have been established to be processed in an obligatory manner, as semantic mismatches modulate gaze behaviour. Individuals spend more time looking at incongruent than congruent objects (Cornelissen & Võ, 2017), in addition to there being no implicit or explicit memory trace of doing so. Earlier, modulation of contextual violations has been shown at around 170ms (Guillaume, Tinard, Baier, & Dafau, 2018) - this was in addition to finding the traditional N300 component. Results therefore are in line with such research, with the accuracy differences in Study 2.1 and N2 amplitude difference in Study 2.2. Furthermore, whilst the counterargument of such early top-down modulation of components would revolve around low-level image statistics in images, the lack of difference in the P1 latency both in the work in this chapter and in related research (Balas & Conlin 2015; Guillaume et al., 2018) does shift the results more towards a top-down influence.

Results observed at the N2pc range are also consistent with face processing theories of the N170 component, which provides evidence for top-down influence in the N1 latency (Eimer & Kiss, 2010), and a general trend that neuronal responses are shaped by world experiences (Sigala & Logothetis, 2002). Recently, Lauer and colleagues (2018) used a method of image synthesis to create scrambled texture that preserved summary statistics of images but discarded global shape information, through the Portilla and Simoncelli model (2000). The robust N300/N400 deflection was elicited by individuals when incongruent objects were placed over both unaltered scenes and their synthesised textures, suggesting that these low-level summary statistics still carry semantic value. This suggestion of neural components being sensitive to artificial textures was also forwarded by Balas and Conlin (2015), where an increased N1 amplitude was found for synthesised textures compared to natural. Results here would suggest something similar, with the extreme violations that trigger increased levels of inhibition doing so because of semantic discrepancies, but with smaller levels of semantic violations (low violation images) not distinguishable from natural images.

Research that has illustrated this N300/N400 deflection would also support results here, as whilst the paradigm encouraged an inhibitory component, the latency of the deflection in comparable to the N300. Deflections in this range have been accredited to contextual violations in images (Mudrik et al., 2010; Mudrik et al., 2014), with syntactic violations eliciting a later N600 effect (Võ & Wolfe, 2013). More recently, Truman and Mudrik (2018) dissociated the closely overlapping N300 and N400, with the former being tied into object identification, and the latter semantic integration. The processes underlying this integration may also be present in results in this chapter. The matching model of object identification (Barr, 2004) suggests that the gist of a scene is rapidly extracted when shown to individuals, where it activates schemas for congruent objects, which are then compared to incoming visual information. This has been supported by fMRI research showing contextual effects in object identification areas and the early visual cortex (Brandman & Peelen, 2017). The differences in accuracy rates in Study 2.1 might therefore be accredited to the ambiguous quality of visual information that is being used in such a comparison, where images that contain contextual violations, such as a fruit that is split into ripe and half ripe portions can clearly be dismissed when compared to semantic knowledge. However, violated images that are visually less distinguishable from existing templates are more easily incorrectly classified.

Limitations

One important limitation to the results in this chapter are the small and unequal sample sizes. Although the small sample size has already been addressed, with similar previous research establishing effects with comparable group numbers (IBs/NIBs = 14/7, Papera & Richards, 2014; IBs/NIBs = 7/12, Papera & Richards, 2017), the low power in both studies here does mean that differences across the groups may have required more participants in order to firmly establish effects. Another factor to contend with is that the increased recruitments of participants was no guarantee of equal groups, with inattentionally blind participants carrying a higher risk for disqualification due to increased EEG artefacts. In order to address this issue, as mentioned in the General Discussion, work will move to categorising participants on working memory capacity to ensure equal group sizes. With results then being discussed with implications for inattentional blindness research.

Conclusion

In summary, the main findings from this chapter are as follows: image quilting constitutes a valid method for creating stimuli for investigating differences to synthesised and natural textures. Secondly, synthesised textures created by such a method can demand more inhibition when presented as a distractor compared to natural textures, but only when synthesised images carry higher levels of distortions. Although this inhibitory process, in the current paradigm, did not depend on working memory capacity, as amplitude was significantly greater in response to high violation distractors across all participants.

Chapter 3. Sensitivity across Working Memory Capacity to Autoregressive Patches

3.1 Sensitivity across Working Memory Capacity to Autoregressive Patches

3.1.1 Introduction

Research Question

The following study will investigate whether neural inhibition to real-world textures is allocated based upon the size of an autoregressive-filled patch within the image, and whether successful allocation is dependent on working memory capacity. The study will introduce a new technique, autoregressive modelling, that provides a more systematic method to introducing salient patches in real-world textures. Furthermore, the study will retain the use of the N2pc range in order to investigate both mean amplitude measures, and a linear trend analysis to investigate differences in incremental allocation of inhibition, or lack of, across working memory capacity groups.

Autoregressive Modelling

Although work in the previous chapter has shown evidence to suggest that image quilting is a viable method for investigating differences across domains such as working memory capacity, and phenomena such as inattentional blindness, work here moves to the use of autoregressive modelling. This reason for this change was the simplicity in manipulating the size of the patches and therefore the overall saliency of stimuli. As the image quilting method created a new image through the rearrangement of existing blocks and then quilted the blocks together through the boundary cut, saliency of the image was then dictated through how similar or different these blocks were when placed next to one another. Consequently, whilst the method offered results that were congruent with the aims of Chapter 2, by creating a semantic saliency with processing power focused on quilting distant image blocks together instead of filling gaps in images, manipulating the intensity of saliency was difficult.

The resultant stimuli from the image quilting process had to ultimately be categorised by participants in a study prior to using the images as distractors in a flanker paradigm. However, autoregressive modelling permitted a compromise between the ability to systematically manipulate saliency across images and the smoothness of patch filling. Instead of focusing processing power on quilting together images blocks, the method used in the current chapter created varying sizes of gaps in real-world image textures and used a forward and backward predictive model to fill in image statistics. Autoregressive modelling was originally established in order to create a figure of merit in model prediction that could be used to distinguish the fit of each model iteration (Akaike, 1969). This figure of merit was proposed to be the final prediction error, formally defined as 'expected variance of the prediction error when an autoregressive model fitted to the present series of *X(n)* is applied to another independent realization of *X(n)'* (Akaike, 1926, p. 244), this is in the model:

$$X(n) = \sum_{m=1}^{M} a_m X(n-m) + a_0 + \varepsilon(n)$$

where *X(n)* is the current process, and $\varepsilon(n)$ represents the level of white noise, and *M* represents the order.

The order of the modelling refers to the *th* autoregressive process, this is to say if a first order autoregressive model is selected then the outcome for that iteration would be based upon regression from points that are a single point apart, specifically *t,* as a representation of time, would be related to $t - 1$. Therefore, a second order regression would therefore be based upon points that are two points apart, so on and so forth. The Matlab implementation of the model relies on a minimisation of the Akaike information criterion (AIC; Akaike, 1974):

$$AIC = logE + 2 * \frac{p + 1}{n}$$

where *p* represents the effective number of parameters used by the fitting procedure, *n* the sample size, and *logE* the natural logarithm (representing the power to which a fixed number must be raised to produce a given number) of the next order reflection coefficient. Using the AIC as a measure of best fit for the model fitting allows for a trade-off between the goodness of fit and the simplicity.

The autoregressive procedure was chosen to create violations in Study 3.1 due to the simplicity in its method of predicting missing values in image statistics. Therefore, instead of manipulating the level of violation, as was the case with the image quilting technique, across images and using behavioural data to validate the different levels, autoregressive modelling allowed for a standardised threshold with the manipulation of saliency being the size of the original patch (see Methods for a more detailed description of the manipulation process and see Figure 3.1 for implementation of the process).

Rationale

The rationale of the current study builds heavily upon work in Chapter 2: to assess whether working memory capacity stores of individuals can predict the efficiency of the allocation of attention to distractors. Moreover, this efficiency of allocation will be tested on a systematically manipulated patch-based approach (Papera et al., 2014; Papera & Richards, 2016; Feldmann-Wüstefeld et al., 2017). Given that amplitude in the N2pc latency, more specifically the P_D subcomponent, has been shown to increase in a linear fashion as a function of working memory capacity (Gasper et al., 2016), the systematic nature of the increasing saliency in the stimuli will provide the opportunity to test whether efficient allocation of inhibition across images is also dependent on working memory capacity. Given limitations outlined in Chapter 2 regarding the classification of participants inattentional blindness based on a one trial paradigm, participants are instead categorised into a high and low working memory capacity group based on their working memory capacity (AOSPAN) scores.

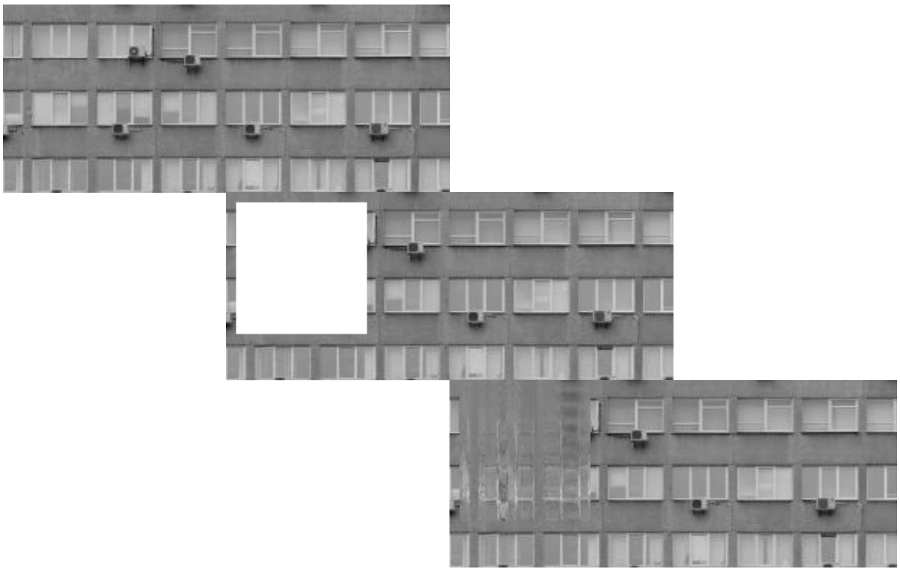


Figure 3.1. Illustration of the autoregressive filling technique, with a sample image of real-world texture, which then has a gap introduced through replacing image statistics with NaN (not a number) values, lastly, the results of the filling technique.

Implications are still discussed with links to inattentional blindness literature, as work in Chapter 2 aligned with the working memory capacity theory of inattentional blindness – where low-capacity resources predict inattentional tendencies due to the lack of resources, and therefore processing. The rationale for categorising participants based on their working memory capacity was that the test represented a much more robust, measurable trait, and can therefore results can be discussed with more confidence. Given the systematic nature of stimuli creation, and the linear relationship between working memory capacity and amplitude in the N2 latency, a linear trend analysis was also conducted to investigate if trends emerge at a certain increment of patch-size.

Hypotheses

Hypotheses will be stated in an order that foreshadows the analyses: firstly, it is hypothesised that the higher working memory capacity group will elicit greater inhibition per patch size in comparison to the low working memory capacity group. This is to say that higher working memory capacity participants will show greater amplitude (P_D) to bigger distractors when conducting a primary task (observing rotation in a pentagon stimulus), as they would be better at inhibiting distractions. Furthermore, a linear trend analysis is predicted to observe a linear trend across the high working memory capacity group, whereby increasing amounts of inhibition is allocated as the size of the image patch increases. This is hypothesised to contrast from the pattern in the low working memory capacity group, where due to the lack of resources, inhibition is inefficiently allocated and represents no sensitivity to the size of the image patch.

3.1.2 Methods

Participants

A total of 20 participants were recruited using a cloud-based participant management software. All had normal or corrected to normal vision and were naïve to the experimental hypotheses. All experimental procedures were approved by the Birkbeck research ethics committee, and informed consent was taken before testing. Participants were excluded due to noisy EEG data (two participants excluded), and for not reaching the reaction time threshold on the AOSPAN task (two further participants excluded). The remaining 16 participants were aged between 18 - 30 (M = 25.5 years, SD = 5; 10 women).

Flanker Task - Stimuli

The flanker task was coded using Matlab (Mathworks) and the Psychtoolbox extension (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). The fixation cross measured 0.9 x 0.9°, each rectangle frame and consequently each distractor measured 4.4 x 2.2° of visual angle. Each contralateral rectangle began at 9° away from the central fixation point, and vertically 5.2° away. The pentagon measured 1.4° from top to bottom, and across at its widest point, degrees of rotation would be 45°, 90°, 135°, or 180°. The monitor used was a Samsung SyncMaster 2233, with display measurements of 1920 x 1080, with a viewing distance of 60cm.

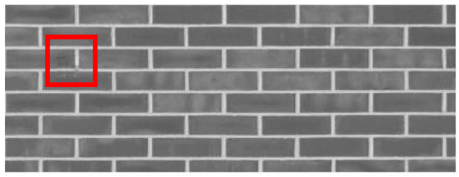
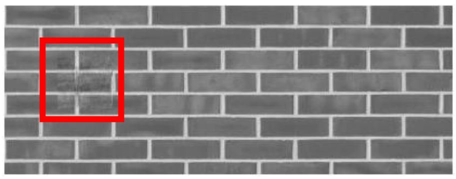
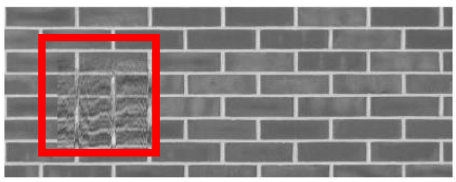
Source images for the autoregression gap filling were taken from a free texture image website (www.texturelib.com) and were selected on the basis of the image having form of contour structure, that is to say images that were more stochastic were avoided as they would not fear well with a gap filling technique that relies on pre- and post-image statistic information to fill in a missing value. Selection resulted in a total of 20 images. The method of implementing the autoregressive patches is detailed in the introduction, however, a quick overview of the processing timeline and the autoregressive technique is given here. Images were first read into Matlab using the *imread* function, where the image data are held as an array, each image was then converted to a greyscale image using the function *rbg2gray*, here the hue and saturation was eliminated for each image whilst retaining the luminance data.

Random coordinates were then generated that were 50 pixels (1.2°) within the borders of the image, as patch that disrupts the edge of an image may carry more saliency than one that does not. These coordinates were generated along the x and y axes and constituted the size of the patch that was to be filled, these patches consequently varied from 20 x 20 pixels to 90 x 90, in increments of 10 pixels along both axes. Resulting in a total of eight patch sizes, not including the control condition of no patch (see Table 3.1 for a full list of patch sizes). These patches were then filled using the *fillgaps* Matlab function, the NaN values in the image array were replaced by the weighted average of the values estimated by forward and backwards prediction (see Table 3.1 for selected example stimuli).

Flanker Task - Procedure

A single trial consisted of three exposures: part one; a fixation screen was shown for 1000ms to enable participants to prepare central fixation, with the screen comprised of all four rectangles and the central fixation cross. Part two: the exposure screen was shown for a maximum of 2000ms or until user input. The exposure screen consisted of the distractor image and the target pentagon, which was shown in either a contralateral or perpendicular fashion. Perpendicular trials were shown every one in 20 trials to avoid repetition, and in perpendicular trials the target was always located laterally. Randomisation was implemented for the selection of image to be used per trial (from the library list of 20 images), size of the patch to be filled, and *xy* coordinates of where the patch would be. The pentagon itself has a 10% chance of rotation, and trials were discarded in the analysis where a rotation occurred. Lastly part three: the exposure screen would be shown again to participants for a randomly generated time between 500-1000ms.

Table 3.1. All patch sizes used in stimuli for the flanker task, with selected examples of implementation of patches in images.

Stimulus Type	Patch Size/pixels	Example Stimuli
Control Image	0x0	
Manipulated Image	20x20	
Manipulated Image	30x30	
Manipulated Image	40x40	
Manipulated Image	50x50	
Manipulated Image	60x60	
Manipulated Image	70x70	
Manipulated Image	80x80	
Manipulated Image	90x90	

Participants were told to fixate centrally throughout the task and to use peripheral vision to conduct processing on the exposure screen. Participants were asked to monitor the orientation of the pentagon, and to press the ‘c’ keyboard letter every time the orientation changed from the default setting, which was a natural upright orientation (see exposure screen in Figure 3.2 part two for the natural orientation). Participants were also told that a distractor would be shown simultaneously as the pentagon, and that they must ignore it as best they could. Participants completed 250 trials in total, separated into blocks of 50 (see Figure 3.2 for single trial sequence).

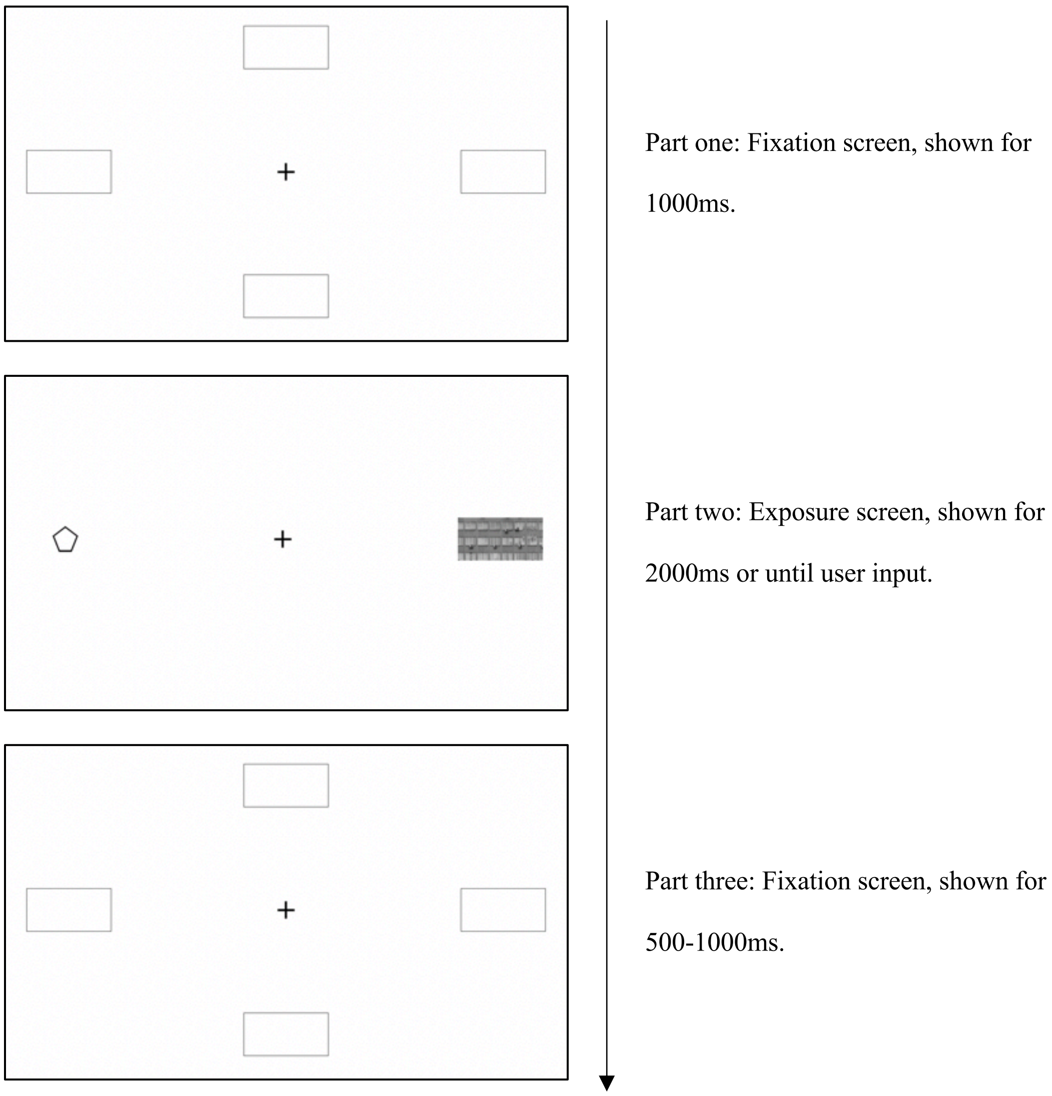


Figure 3.2. Trial sequence for the Flanker Task.

Flanker Task – Factors

There was a single independent variable to note: the size of the image patch, which consequently contained nine levels, ranging from no patch, then from a 20x20 pixel patch to a 90x90 pixel patch in increments of 10x10 pixels (see Table 3.1 for a full list). Participants were then separated by a median split based on their working memory capacity scores, measured through the AOSPAN, results in a high and low working memory capacity group. Measurements of N2pc amplitudes were averaged within levels of the independent variable, and then averaged within both the high and low working memory capacity groups to compare grand averages (see *Flanker Task - EEG Recording and Analysis* for details).

Flanker Task – Relevance

The relevance for the flanker task builds upon task relevance from a similar version used in Study 2.2, where inhibition was compared across inattentional blindness groups. In the current study, participants are categorised on the basis of their high and low working memory capacity, through a median split. The flanker task consequently allows an investigation into the ability to inhibit distractors based on the size of a saliency patch in a real-world texture. The size of the patch within the image stimuli were manipulated in order to provide more systematic increments compared to Study 2.2, this increased level of control therefore brings more sensitivity to finding a difference across the working memory capacity groups.

Given the hypothesis proposed, that high working memory capacity participants will be able to increase inhibition based on patch size, this incremental manipulation can therefore be compared across both groups, potentially showing a point at which inhibition begins. The nature of the paradigm itself is also congruent with the measurement of the N2pc component with contralateral stimuli. In regard to the analyses conducted, the comparison of mean amplitudes will aid in comparing the level of inhibition allocated at each level.

Flanker Task - EEG Recording and Analysis

EEG was recorded with silver electrodes mounted on an elastic cap (Easy-Cap) from 28 electrode positions (FPz, FP1, FP2, Fz, F3, F4, F7, F8, FCz, FC1, FC2, FC5, FC6, Cz, C3, C4, Cz, CP1, CP2, CP5, CP6, Pz, P3, P4, P7, P8, O1, O2), according to the International 10-20 system. Horizontal EOG was recorded bipolarly from the outer canthi of both eyes. Electrical impedances were kept below 5 kΩ, with the impedances of the earlobe electrodes as equal as possible. The bandpass was 0.01 – 40 Hz and sampled at 500 Hz using a SynAmps amplifier (NeuroScan), and epoched to 2000ms windows with a baseline of 100ms. Artefact correction was completed using Independent Component Analysis (ICA), the justification being that a select number of participants had a large proportion of artefacts in the data caused by eye movements, therefore using the original automatic threshold detection approach would have resulted in a larger than necessary number of trials having to be rejected.

The ICA script was run in two instalments, in the first instance, the script was run to identify trials that could be flagged as inconsistent with normal data collection. The criteria to which this was judged was based on the amount of divergence from normal values; extreme values that surpassed the threshold of 75µV, abnormal trends that are due to linear drift, where a straight line is fitted to the data and is flagged if the slope of the data exceeded a threshold of 50µV. Improbable data, where the probability distribution of values across data epochs are first computed and compared across the dataset, where the probability threshold was four standard deviations of the mean probability distribution. Abnormal distributions in the data were identified through the kurtosis of the distribution, where high kurtosis represents an abnormally high frequency of peaks in the distribution, distributions that were further than five standard deviations from the mean kurtosis were flagged as abnormal. Lastly, data epochs were also flagged according to abnormal spectra (Delorme, Makeig, Jung, & Sejnowski, 2001), here values were computed as a function of relative change to baseline (dB).

All flagged epochs were inspected manually and were deleted on the basis of them being flagged by the aforementioned criteria, although the probability of deletion was increased with a higher number of separate flags. After deletion, a second wave of ICA was run in order to identify components that were manually inspected and excluded. Eye-artefacts were identified on by a smooth decreased in the EEG spectrum, a far-frontal projection in the scalp map, and the frequency of eye movements in the component image. Furthermore, brain components were identified through dipole like scalp maps, spectral peaks at typical EEG frequencies, and regular activity throughout trials. Components removed were more likely to be early in the transformation, as eye artefacts tended to be large, and an average of 4 components were removed from the dataset per participant. All analysis was conducted on the corrected data.

In order to compute N2pc amplitudes, activity was averaged from the O1, P7, and P3 electrodes (left cluster) and the O2, P4, and P8 electrodes (right cluster). These clusters were then used to compute difference waves by subtracting the response for the ipsilateral hemisphere from the contralateral hemisphere for the respective cued trials. For instance, if the distractor appeared on the left, the activity from the right cluster would be subtracted from the left to compute the difference amplitude. These difference waves were then averaged across trials for each corresponding lateralisation of distractor image. The latencies used were taken from Study 2.2, as both paradigms did not differ in nature.

AOSPAN Task – Stimuli and Procedure

The AOSPAN was identical to previous versions used in this thesis and has been described in Study 2.2.

AOSPAN Task - Factors and Relevance

The AOSPAN task factors and relevance remained the same as in Study 2.2.

3.1.3 Results

Median Split of Working Memory Capacity Group

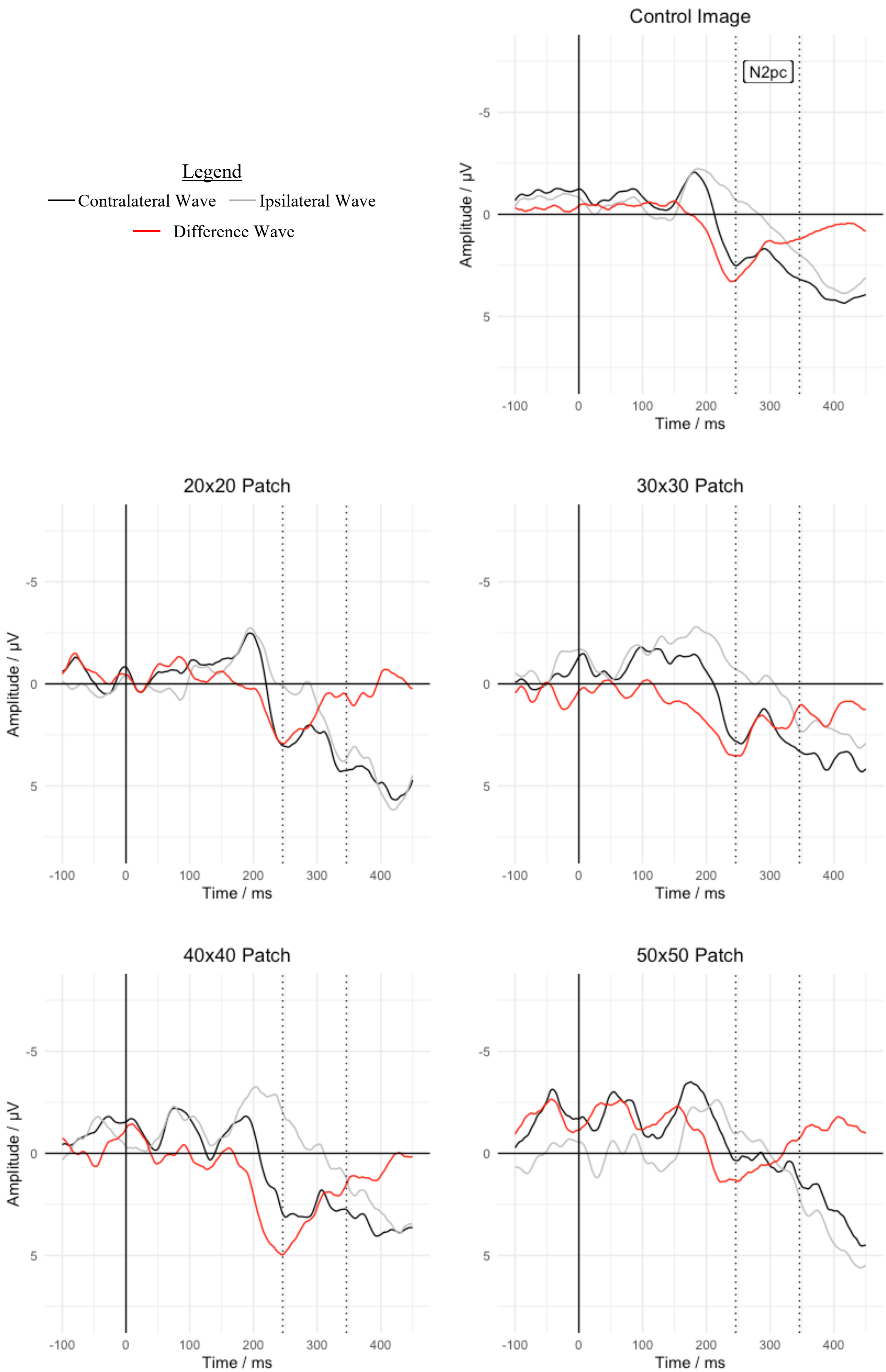
A median split of working memory capacity, measured through the AOSPAN task, was conducted in order to categorise participants into high and low (median = 44, range = 62).

N2pc (246-346ms)

To begin with, laterality of the component was tested using the same method as in Chapter 2, amplitudes were submitted in a within subject ANOVA, with contralaterality (contralateral and ipsilateral) and patch size as within subject factors. Bonferroni corrected comparisons were then used to assess significance between contralateral and ipsilateral waves for each condition. A main effect of contralaterality was observed, $F(1,13) = 35.50$, $p < 0.01$, $\eta_p^2 = 0.73$, with the contralaterality and patch size interaction approaching significance, F(8,104) = 1.94, p = 0.06, $\eta_p^2 = 0.13$ (see Table 3.1 for comparisons). Using the time window identified in Study 2.2, mean amplitudes were taken from the N2pc range and compiled into a mixed ANOVA, with patch size as the within subject factor, and working memory capacity as the grouping factor. An approaching significant effect was observed in patch size, $F(8,96) = 2.00$, $p = 0.05$, $\eta_p^2 = 0.14$, power = 0.79, with Mauchly's test of sphericity not violated X^2 (35) = 49.33, $p = 0.08$ (see Figure 3.3 for waveforms at each patch size). However, Bonferroni corrected pairwise comparisons revealed no significant differences, *p*'s > 0.56. Furthermore, no interaction between patch size and working memory group, or a between groups effect of working memory capacity was observed *F*'s < 1.44, *p*'s > 0.18 (see Figure 3.4 for mean amplitudes across working memory capacity groups).

Table 3.2. Bonferroni Comparisons for laterality for each condition.

Patch Size	*Contralateral / µV*	*Ipsilateral / µV*	*t value*	*p value*
Control	2.32	0.48	2.94	0.24
20x20	2.93	1.40	2.45	0.57
30x30	2.37	0.19	3.49	0.06
40x40	2.75	-0.26	4.82	<0.01
50x50	0.47	0.05	0.66	1.00
60x60	1.74	1.28	0.75	1.00
70x70	2.41	0.80	2.57	0.48
80x80	1.57	0.52	1.68	0.96
90x90	2.55	0.49	3.30	0.10


Legend
Contralateral Wave
Ipsilateral Wave
Difference Wave
Control Image
N2pc
20x20 Patch
30x30 Patch
40x40 Patch
50x50 Patch
Amplitude / µV
-5
0
5
Time / ms
-100
0
100
200
300
400

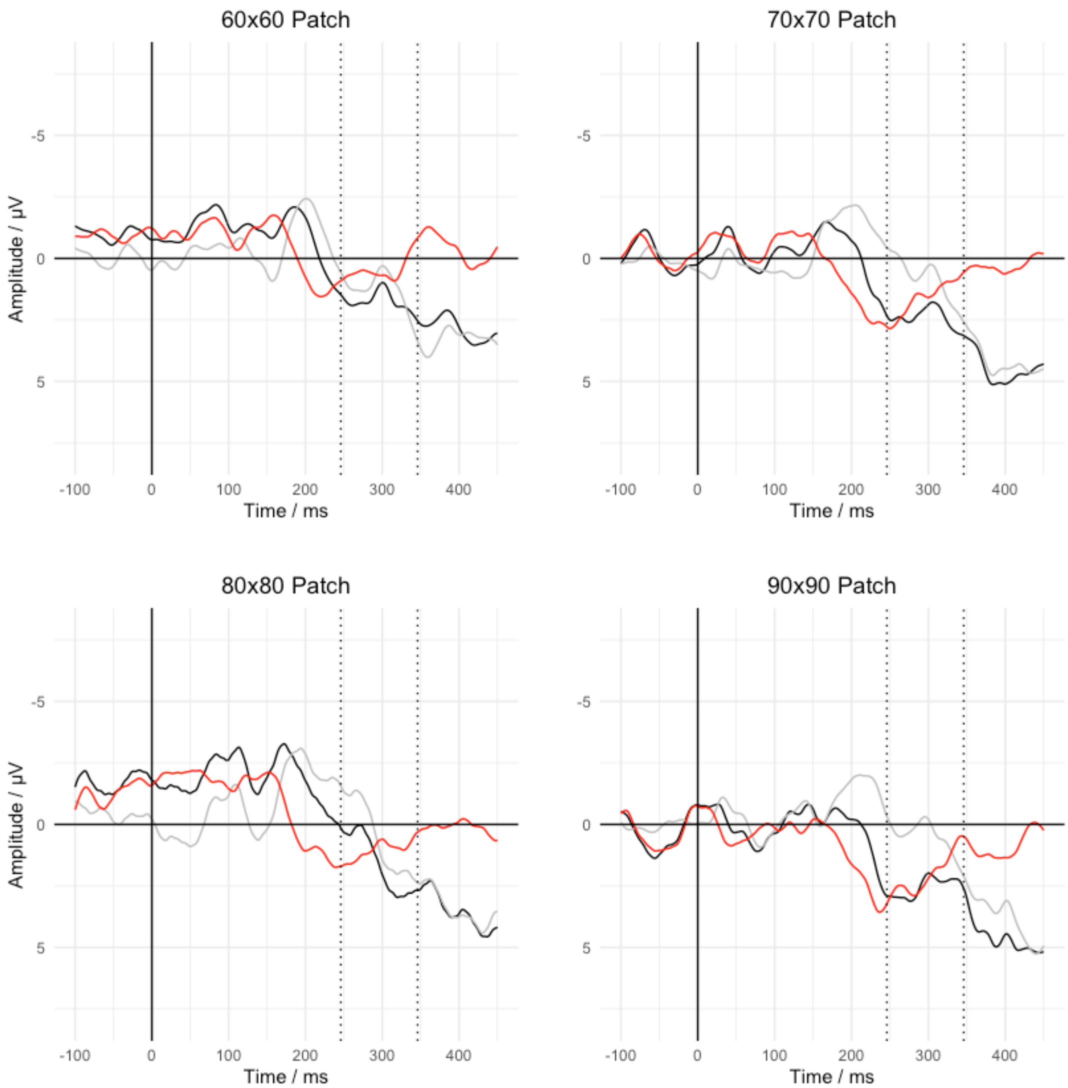


Figure 3.3. Waveforms aggregated over entire sample, separated by patch size. Negative is plotted upwards for amplitude, waveforms are averaged from clusters specified in *Flanker Task - EEG Recording and Analysis,* and 0ms represents the onset of the distractor stimuli screen (Figure 3.2 part two). Dotted lines represent the N2pc window.

Linear Trend Analysis

A linear trend analysis was also conducted in conjunction with the ANOVA to assess whether working memory capacity groups differed in their reaction to systematically increasing patch sizes. However, no significant linear trends were present in either the main effect of patch size of interaction between patch size and working memory capacity groups, F's < 1.11, p's > 0.31.

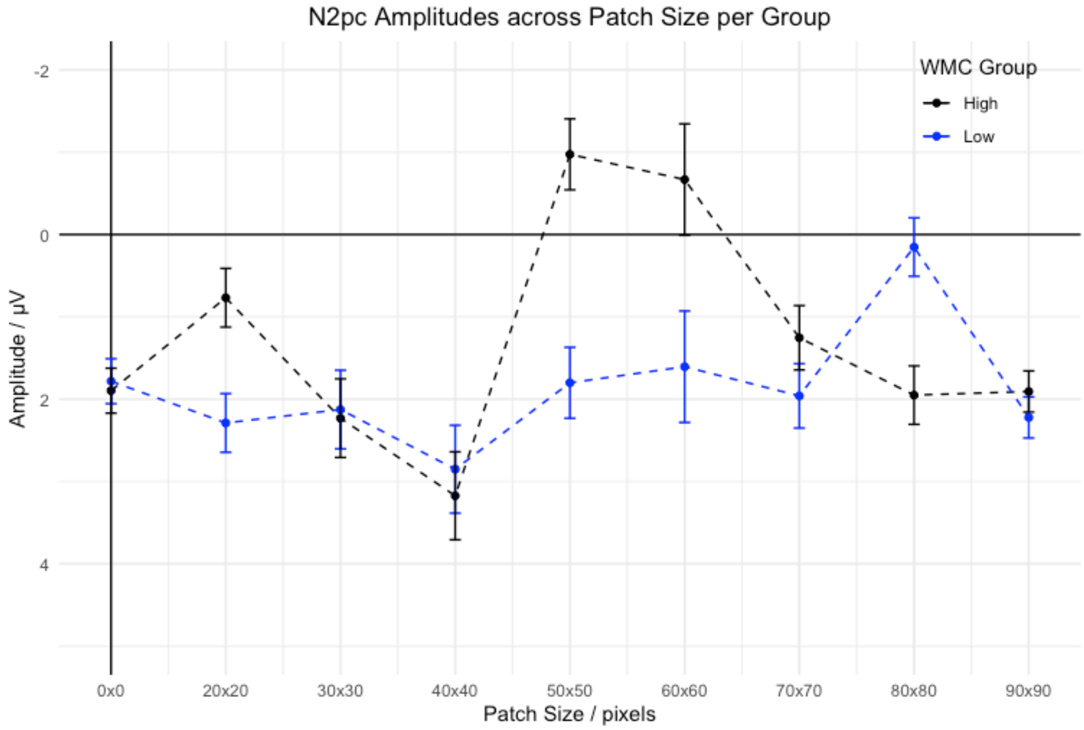


Figure 3.4. Mean amplitudes for each patch size by working memory capacity group, negative is plotted upwards for amplitude, and bars represent standard error of the mean.

3.1.4 Discussion

In summary, the work in this chapter has built upon work from the first experimental chapter, using a more systematic method to introduce patches that carry a level of saliency that individuals must inhibit to perform the primary task. Results from the initial analysis are however inconclusive, as no main effect of violation size was found, or a main effect of the working memory capacity grouping variable, as per the hypotheses. Although differing patterns were observed across working memory capacity groups along the patch size spectrum (see Figure 3.4), Bonferroni corrected comparisons did not reveal any significant differences. However, most importantly, the Bonferroni comparisons of contralaterality did not reliably show a significant effect. Therefore, results regarding inhibition and the allocation of attention cannot be made conclusively as the paradigm itself was not successful in eliciting the corresponding component. The following sections will speculate as to the reasons for the emerging patterns across the two groups and the impact of the methods on previous research, both in this thesis and in published research. However, the sections will also emphasise limitations, namely the nature of the paradigm used, and the contribution to the lack of significant findings.

Inhibition Across Violations

The results of Study 2.2 (previous chapter using image quilting methodology) found greater negative amplitudes allocated to distractors that contained high levels of contextual violations compared to images without such violations. Images that contained low levels of violations did not present any significant differences across the sample, thus representing a pattern where extreme violations are required in order to influence amplitude levels. However, in the current study a different trend emerged: average amplitudes did not differ significantly across the greatest level of violation and the control image (no violation), as was the case in Study 2.2. Instead, amplitudes are suggestive, although not significant, of a greater sensitivity to violation size in individuals with greater working memory capacity, that starts at images with a 50x50 pixel violation.

Whilst not significant, this potential trend would not have been possible to isolate in Study 2.2 due to the harsher, arbitrary categorisation of stimuli (high, low, natural), whereas, in the current study the spectrum of violations allows for a greater sensitivity to different trends, illustrating the benefit of the autoregressive technique and the consequent ability to manipulate patches systematically. The suggestive trend seen in high working memory capacity participants can then be explained through the nature of the paradigm. Given the linear pattern in high working memory capacity participants from the 50x50 violation size onwards, it may be the case that the 50x50 violation size only reflects a moderate violation in relation to the experimental spectrum (of the varying patch sizes within this study). Objectively, it may reflect the minimum size of distortion that is indexable through neural suppression when shown as a distractor.

The flanker paradigm employed here meant that distractor images began at a distance of 9° away from the central fixation point, with the distractor itself constituting 4.4° across, lastly the moderate violation size of 50x50 pixels would translate to 1.2 x 1.2° of visual angle. For instance, research investigating the P_D and working memory capacity has used singletons of 3.4° diameter at a visual angle of 9.2° away from the fixation point (Gasper et al., 2016). With visual acuity dropping steadily the further away from central fixation the stimulus is placed (see Figure 3.5), it may be the case that the size of the violation may have had to reach a threshold before it could be processed and inhibited. This was consequently only of importance to high working memory capacity individual who would have had the additional resources to process and efficiently adapt the allocation of inhibition per distractor.

It is important to note that these trends are suggestive, as a significant interaction was not observed. However, the indiscriminate allocation of attention by the low working memory capacity group is reflective of a low working memory resource pool. Whereas a trend did emerge in the high working memory capacity group, past a threshold of violation, the low-capacity group may have been maximally taxed by the task itself and thus not able to allocate attention differentially based on the violation size, as seen in Figure 3.4. It is important to note that the processing of natural textures and their synthesised patches or counterparts is not a passive process and requires the representation and reconstruction of natural inputs in receptive fields of early visual areas (Olshausen & Field, 1996), and comparative processing of the power spectrum slopes of natural images and noise patterns (Field, 1987).

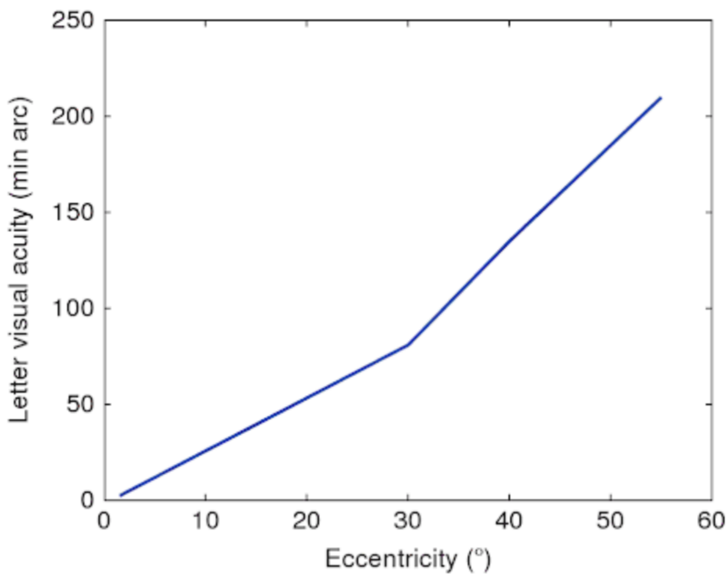


Figure 3.5. Visual acuity of letters presented in peripheral vision across degrees of eccentricity. Adapted from ‘The Retina and its Disorders’, by Besharse, J. C., and Bok, D., 2011, Oxford: UK.

Research that has used contextual violations in images not as distractors, but in visual search paradigms, have found N1 or N300 and N400 effects for incongruent scenes (Balas & Conlin, 2015; Dyck & Brodeur, 2015; Lauer et al., 2018; Mudrik et al., 2010; Mudrik et al., 2014; Truman & Mudrik, 2018; Võ & Wolfe, 2013), in addition to finding lower accuracy and/or longer reaction times for such incongruent trials (Ganis & Kutas, 2003; Mudrik et al., 2010; Mudrik et al., 2014; Truman & Mudrik, 2018). These results have been a product of binary categorisation in stimuli, with the stimuli either congruent or incongruent, not on a gradient of increasing saliency. The lack of main effect from this study therefore is not congruent with such evidence, however, this may carry more ramifications for the method used as opposed to the direction of previous research.

The Autoregressive Technique

The reason for using the current technique in creating stimuli over image quilting, as in the previous chapter, was in order to create stimuli in a more systematic manner, one where violations could be controlled and created on an incremental basis. Whilst related research has implemented the Portilla-Simoncelli model (2000) of texture synthesis for stimuli creation (Balas, 2005; Balas, 2012; Balas & Conlin, 2015; Freeman & Simoncelli, 2011; Lauer et al., 2018), the experimental comparison was across synthesised and natural. The autoregressive technique used here permitted the creation of stimuli where violations could be manipulated by size, and comparisons of P_D could made along size.

Furthermore, texture synthesis algorithms aim to preserve local image statistics, for instance correlations across position, orientation, and scale (Balas & Conlin, 2015). The autoregressive technique bears more resemblance to saliency patches created through the use of a genetic algorithm (Papera et al., 2014; Papera and Richards 2016), where saliency can be manipulated through smaller increments. However, in the mentioned research working memory capacity was only used to as a predictor of inattentional blindness and not for the amplitude of ERP components. The results here therefore demonstrate a different strategy emerging across working memory capacity in inhibiting texture distractors that contain varying levels of patch violations.

Given the results from Study 2.2, research into summary statistics, and the N1 and N300 (Balas & Conlin, 2015; Lauer et al., 2018), it may be the case that the filling in of objects using the autoregressive technique does not carry as much top-down influence on scene processing. Specifically given the related research mentioned, which seem to suggest only methods that preserve the local statistics, and consequently the semantic value, in images of textures produce neural differences across the N1 and N300. There are two potential reasons that may contribute to this issue in the current study, firstly the images were converted to greyscale and therefore statistics of the images may not have carried enough variety to create realistic contextual violations, as compared to image quilting in the previous chapter. Secondly, given that the autoregressive technique specifically relies on the existing image statistics to predict missing values, it could not in turn compensate for producing new statistics that carried the variety for complex patches.

The technique, like all methods, carries both benefits and drawbacks in its results. This study was the first to apply the autoregressive technique to examine differences across working memory capacity, and therefore examine the effects of such benefits and drawbacks. When amalgamating the results of both this chapter, with the autoregressive technique, and the previous, with the image quilting, work has helped to further the knowledge around the tools available in understanding the limits of working memory capacity and inattentional blindness in real-world stimuli.

Limitations

The first limitation to be discussed regards the nature of the paradigm itself. Where in Study 2.2 the distractor was shown laterally to a central task, in the current study both the target (pentagon) and the distractor (image) were shown laterally, either side of the fixation cross. The paradigm design emulated a number of studies that contained stimuli on either side of a central fixation cross (see Li, Liu, & Hu, 2017; Luck et al., 2006). Such displays use trial instructions to dictate which stimulus acts as the target and which the distractor, with the N2pc being seen as more negative in the left hemisphere for targets in the right visual field, and vice-versa. However, in the current study the placement of both the target and distractor lateral to the fixation cross may have caused competing bilateral signals. This would have been especially pertinent if attentional focus was first directed to the distractor before inhibition, with inhibition acting as an attentional reset (Sawaki et al., 2012).

Such processes then complicate the isolation of distractor positivity, with the initial prediction of the study that inhibition would solely be allocated to the distractor and attention to the target, with varying degrees of amplitude dependent on manipulation. This is clearly represented in the lack of a contralaterality by patch size interaction in the study. The study would have benefitted from a paradigm that simplified exposure of the autoregressive patches, especially given that the high sensory level of the stimuli would have generated more activity compared to low-level singletons for instance. Whilst this could have occurred through the removal of the rotating pentagon task, and thereby presenting only a distractor with a fixation cross, the question then would have been whether the paradigm would have exhausted resources of participants – which was central to the theme of this thesis.

There is therefore a myriad of restricting factors when attempting to extrapolate research in inattentional blindness, working memory capacity, and electrophysiological correlates from stimuli that represent basic textures (Papera & Richards, 2016) to those that reflect texture seen in the real world. Whilst the current and previous chapter have made contributions to the exploration of varying methods to use when investigation such phenomena. The following chapters will focus on differing strategies when tracking stimuli and potential implications for the inattentional blindness screening task.

Conclusion

In conclusion, results in this chapter build upon the exploratory methods work in Chapter 2 regarding the creation of stimuli to use in paradigms investigating working memory capacity and attentional processes. The approach taken was done so in order to firstly manipulate images in a more systematic fashion, this is to say that instead of allowing an algorithm to produce artificial images within a range of error tolerance (Study 2.2), a more regulated method was used. The categorisation of error levels was also more systematic, increasing in a linear fashion, as opposed to being ranked on the basis of behavioural accuracy. Whilst results of the current study did show that autoregressive patches can be explored as a method to investigate attentional process, the results themselves were not congruent with initial hypotheses. No main effect of violation size or of the working memory capacity grouping variable was observed, neither were any interactions. However, when taken alongside the aforementioned limitations of the study design, work in this chapter has contributed to the exploration of methods that incorporate real world images into testing across working memory capacity groups.

Chapter 4. Motion Information in Target Tracking across Working Memory Capacity

4.1 Motion Information across Working Memory Capacity in a Novel Tracking Task

4.1.1 Introduction

Research Question

The following study aims to investigate whether working memory capacity limits drive differences in the behavioural approach to tracking targets. The aim specifically is to investigate whether motion information is used to predict trajectories in a proactive manner by individuals that have a surplus of resources. The following study will introduce a novel tracking paradigm that requires the tracking of a target that carries a propensity to deviate unnaturally. Performance when the target deviates and when it runs predictably will be compared across working memory capacity groups to observe whether a reliance on motion information is present.

Visual Tracking

The requirement to track items in our visual environment whilst concurrently undertaking secondary tasks is a compound skill required for everyday tasks such as navigating through complex scenes. Mechanisms of tracking have been proposed that implicate the role of pathway prediction of targets, however, it is debated to what degree individuals use such motion information when tracking. The requirement to predict trajectories does not solely rely on the input of higher order goals, as a need to predict trajectories in order to foveate to a moving object is also required in everyday life, this is seen in everyday tasks such as avoiding collisions in dynamic situations.

Both humans and monkeys are able to accurate saccade to linearly moving targets (Gellman & Carl, 1991; Guan, Eggert, Bayer, & Büttner, 2005), thus suggesting that the oculomotor system does generate predictions as to where targets will be. There has shown to consequently be neural overlap and interaction between the visuomotor circuits for saccades and pursuit (Krauzlis, 2004, 2005). However, it is still unclear as to what degree predictive processes occur in individuals when tracking, and whether such processes are used consistently or in conjunction with other approaches. Research around the subject can be categorised into a location information perspective or a motion information perspective. The location information hypothesis argues that when a target moves, they are compared to the last remembered location, and the identification of the target is made by approximating how close it is to the last remembered location (Keane & Pylyshyn, 2006).

Conversely, the motion information hypothesis claims that targets are instead tracked through the use of both location information, in order to assess starting positions, and motion information to then extrapolate to future positions (Fencsik et al., 2007). Importantly, proponents of the extrapolation/motion information hypothesis propose that while a complete reliance on location information may be preferential as a default (Keane & Pylyshyn, 2006), motion information can be utilised when required to do so (Fencsik et al., 2007). This switching to the need to extrapolate carries tangents to real world settings, such as the need to extrapolate car positions when driving in order to assess danger. It further has implications as to whether a reliance on one approach is dependent on working memory capacity resources and whether this plays a role in screening paradigms such as the inattentional blindness screening task used previously in Chapter 2.

Iordanescu and colleagues (2009) have found evidence for dynamic allocation for the spatial distribution of attention in multiple target tracking in a demand-based manner, suggesting that whilst mechanisms for multiple target tracking can be applied in such a manner, differences within application can be a product of working memory capacity, as seen with inhibitory processes (Vogel et al., 2005). Although parametrical factors have been shown to dictate whether motion information is used, such as when location information is continuously available, there is less of a reliance on motion information (Horowitz, Birnkrant, Fencsik, Tran, & Wolfe, 2006). This is also seen with smaller target loads (Fencsik et al., 2007; Iordanescu et al., 2009). Research mentioned points to motion information being implicated when targets are no longer visible, in order to predict where they will be, what is more pertinent to the aims here, and implications to inattentional blindness research, is whether differences in strategy emerge when targets are constantly visible.

Research on the location/motion debate with constantly visible targets has found that when texture movement of a target opposes the actual movement of the target itself, tracking is compromised (St. Claire, Huff, & Seiffert, 2010), suggesting a constant reliance on motion information, as the incongruent nature of movement disrupts tracking accuracy. Although this effect disappears when the rate at which targets move are not consistent (Vul, Frank, Tenebbaum, & Alvarez, 2009). When such factors are controlled for, performance in tracking targets that move in a predictable fashion outperforms unpredictable movement (Howard, Mason, & Holcombe; 2011; Howe & Holcombe, 2012), suggesting a reliance on motion information. This superior performance in tracking targets with predictable pathways is also observed when eye movements are controlled for (Luu & Howe, 2015), given that eye movements aid extrapolations (Zhong, Ma, Wilson, Liu, & Flombaum, 2014).

Amid the debate around whether location information is solely used to track targets, little research has been conducted as to if the use of such information is dependent on working memory capacity. Specifically, given that this thesis began with categorising participants based on an inattentional blindness paradigm, where targets were continuously visible, there is a rationale to therefore assess whether a participant's approach is dependent on their capacity limits. Ramifications could help to explain why individuals with a lower capacity notice unexpected changes to stimuli, whereby they do not actively track but instead use location information to estimate target positions when required, freeing up resources to meet additional demands.

Rationale

The current study attempts to isolate behavioural differences in object tracking through a novel paradigm. Participants are required to track a single object whilst completing a secondary visual task to tax resources, akin to the inattentional blindness screening task. The unpredictable movement of the target will allow investigation as to what degree participants are relying on motion information, as greater distance lost when the target moves unpredictably is suggestive of a reliance on motion information. The paradigm will therefore isolate behavioural differences in approaches to tracking across levels of working memory capacity, where if differences do exist, then there would be implications for paradigms such as the inattentional blindness screening task, which categorise participants based on tracking performance, without acknowledging the differing approaches taken.

Hypotheses

In the current study it is hypothesised that in non-deviating phases of the trial, participants with low working memory capacity will exhibit less efficient tracking than the high working memory capacity group. The lack of resources would result in a tracking performance not as efficient and therefore one that loses distance on the tracked target. However, if motion trajectories are being used to predict pathways by high working memory capacity individuals, then deviating phases would show a bigger impact for those with high compared to low working memory capacity, as the latter rely on a more reactive measure for tracking as opposed to a proactive one. In regard to the paradigm used, this will manifest itself through greater distance lost in non-deviating phases by the low working memory capacity group and greater distance lost in deviating phases by the high working memory capacity group. Post-hoc power analyses are also included, calculated through the SPSS software option.

4.1.2 Methods

Participants

A total of 24 participants were recruited using a cloud-based participant management software. All had normal or corrected to normal vision and were naïve to the experimental hypotheses. All experimental procedures were approved by the Birkbeck research ethics committee, and informed consent was taken before testing. Participants could be excluded for not reaching the reaction time threshold on the

AOSPAN task (no participants excluded). The participants were aged between 18 - 54 (M = 35 years, SD = 15; 14 women).

Tracking Task - Stimuli

The tracking task was developed using Matlab (Mathworks) and the Psychtoolbox extension (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). The monitor used was a Samsung SyncMaster 2233, with display measurements of 1920 x 1080, with a viewing distance of 60cm. The task consisted of three types of stimuli denoted by colour; a red cursor square controlled by the participant, a black target square, and blue distractor squares. All squares subtended 0.95 x 0.95°, moving at a rate of 2.19° per second, rebounding off the screen boundary but not off other squares. The random deviations of the black target square were computed by the substituting of coordinates that would produce a random change in a horizontal, vertical, or diagonal fashion, but with velocity kept constant. The entire visual display subtended to 46.7 x 31.9°.

Tracking Task - Procedure

The tracking task had two practice sessions, to begin with, participants were shown the red cursor square with no other stimuli. Participants were instructed to practice moving the red cursor square with the keyboard controls; arrow keys for regular movement and the keys ‘q’, ‘w’, ‘a’, and ‘s’ for diagonal movements – this session was untimed and was ended when the participant felt comfortable with the controls. This initial session was followed by another practice session, where 10 trials were completed, these trials were identical to the main experimental trials. The experimental trials lasted 20 seconds and began with a screen prompt which the participant had to trigger in order to begin the trial. Stimuli were presented on screen, with the red cursor square always presented centrally and black target square presented at a maximum of 3° apart. The blue distractors squares, if present on the trial, would be distributed randomly.

Movement of the black target square and blue distractor squares (if present) occurred immediately and in a random linear fashion, with rebounds occurring off the screen edge but not off other squares. In every trial, the black target square would randomly deviate three times, distributed randomly within the trial, with each deviation separated by at least 1000ms so that two deviations did not amalgamate. The blue distractor squares varied from none to five and could randomly change into a blue circle for 1000ms before changing back, these square-to-circle changes could vary from none to eight within one trial. At the end of the 20 second trial a screen prompt was shown asking participants how many blue square-to-circle changes they observed (see Figure 4.1 for example trial sequence).

Prior to the task, participants were instructed to follow the pathway of the target black square as accurately as they could through movement of the red cursor square. They were asked to simultaneously monitor the blue distractor squares, and to observe any square-to-circle changes. Participants were told that three deviations in the trajectory of the black target square would occur in every trial, in addition to the number of potential blue distractor squares present and the number of potential square-to-circle changes. Participants completed a total of 60 trials, separated into blocks of 20.

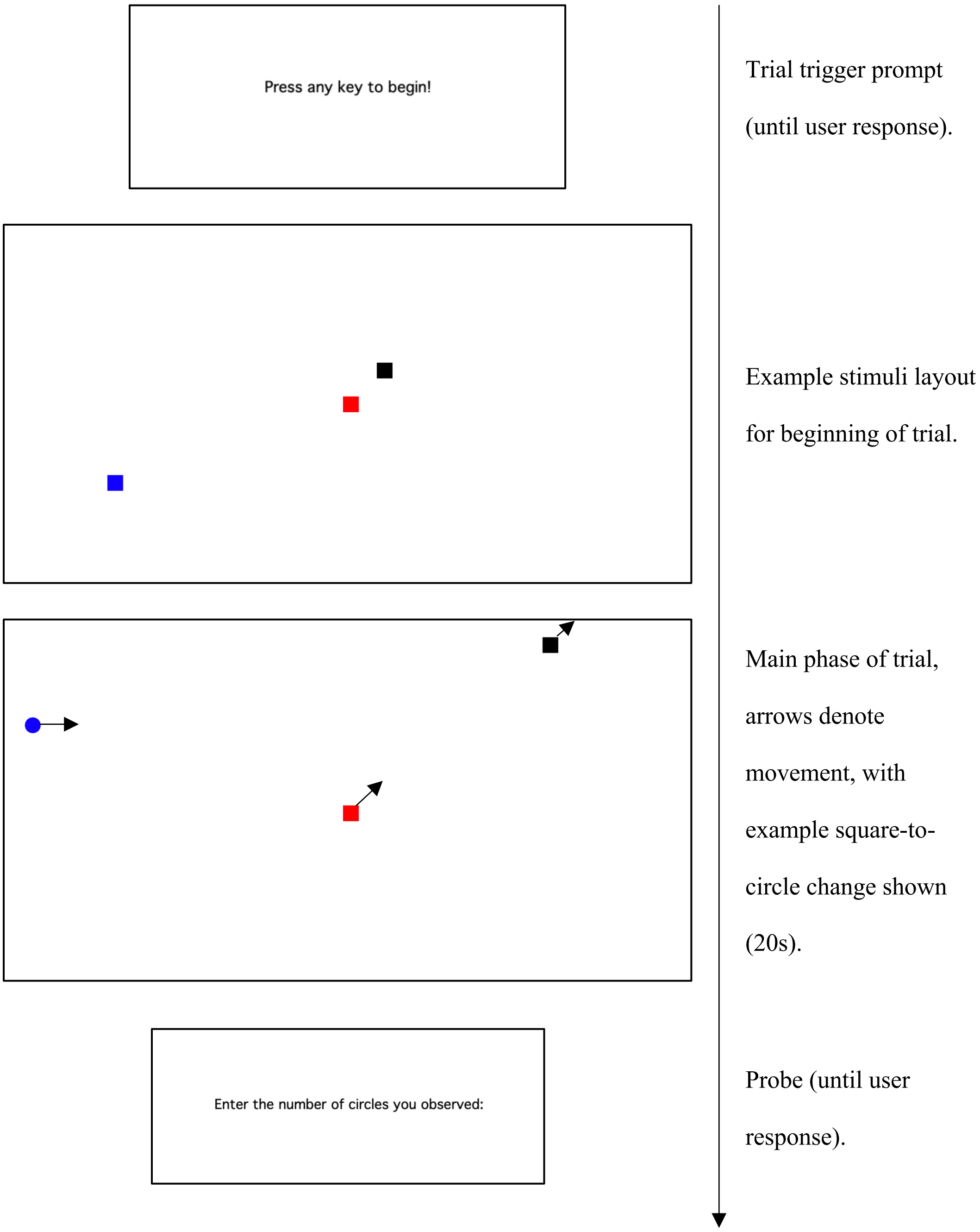


Figure 4.1. Trial sequence for the behavioural tracking task, shown with two instances of the tracking period, the first with a single distractor (blue), and the second when the distractor temporarily changes to a circle.

Tracking Task – Factors

There were two independent variables in the tracking task; trial phase, with the black target square either eliciting an unnatural deviation or not (both occurring within a single trial), and distractor square load, ranging from no squares to five. Two measures were taken from the tracking task, first, accuracy on the square-to-circle changes, measured through the answer given at the end of trial probe. Secondly, a measure of spatial gain was calculated to assess the level of gain or loss achieved through each phase of the trial, it was computed through subtracting the mean pixel distance between the black target square and red cursor square of the last 10 timepoints (equates to a tenth of a second) from the first 10, this was done for each deviating and non-deviating phase, resulting in six measurements per trial. A more negative number reflected more distance lost, whereas a more positive number reflected less distance lost. The measurement allowed for an assessment in to tracking performance throughout each phase of a trial, as opposed to a single probe method that details end performance.

Tracking Task – Relevance

The function of this tracking task was to isolate whether individuals with different levels of working memory capacity differ in their overt tracking patterns and whether potential differences are enhanced under load. Given that the inattentional blindness screening task used in Chapter 2 is essentially a visual tracking paradigm, the tracking task used here with the inclusion of the deviations in the target trajectory, aims to assess whether a proactive approach is taken to tracking by higher working memory capacity individuals. If this is the case, higher working memory capacity individuals would lose more pixel distance in the deviations, as a reactive approach would elicit more successful tracking when the target unpredictably deviates. The addition of the blue distractor squares, and specifically the square-to-circle changes, were introduced in order to emulate the dual-task nature of the inattentional blindness screening task used in Study 2.1. As in the inattentional blindness screening task, participants had to not only track their target letters amongst distractor letters, but also count the number of times the target letters bounced off the boundary edge.

AOSPAN Task – Stimuli and Procedure

The AOSPAN was identical to previous versions used in this thesis and has been described in Study 2.2.

AOSPAN Task - Factors and Relevance

The AOSPAN task factors and relevance remained the same as in Study 2.2.

4.1.3 Results

Median Split

Participants were grouped using a median split of their AOSPAN scores (median = 53, range = 71).

Accuracy

An ANOVA was run on the accuracy rates with workload (ranging from one distractor to five) as a within subject factor and AOSPAN group as the between subject factor. Post-hoc power values were computed, and reported, for selected effects from SPSS. Both the main effect of workload and the interaction between AOSPAN group and workload (Figure 4.2) came out non-significant; *F*s < 1.71 and *p*s > 0.15. The between subject factor of AOSPAN group was also observed as non-significant, $F(1,22) = 0.31$, $p = 0.58$, $\eta_p^2 = 0.01$, power = 0.08.

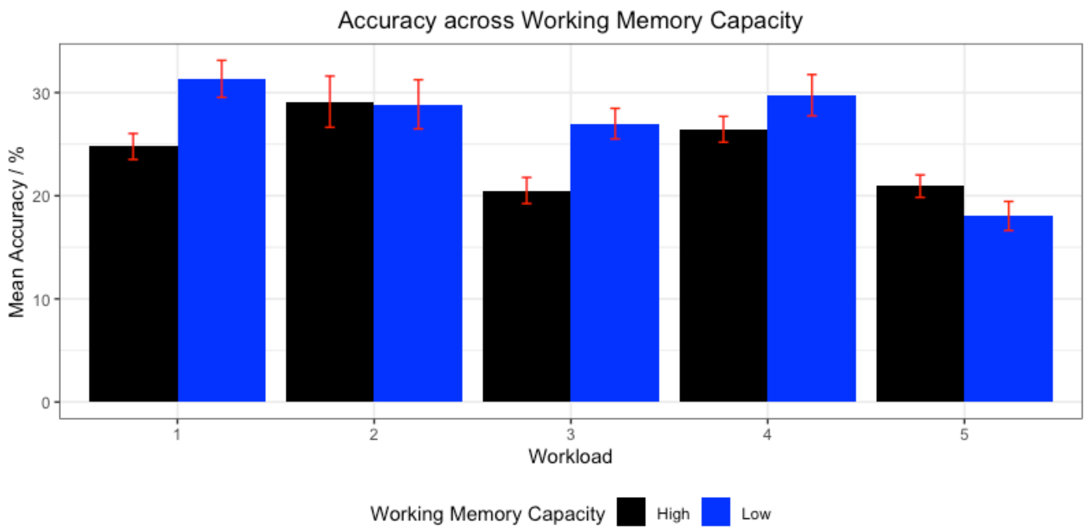


Figure 4.2. Mean accuracy across of workload, across both working memory capacity groups, bars represent standard error of the mean.

Spatial Gain

A mixed ANOVA was run with within subject factors of phase (deviating and non-deviating) and workload (ranging from no distractor squares to five), with AOSPAN grouping as the between subject factor. Post-hoc power values were computed, and reported, for selected effects from SPSS. A significant main effect of phase was found, F(1,22) = 16.47, p = < 0.01, η_p^2 = 0.43, power = 0.97, with deviation phases producing a greater gain in distance (M = -8.39 pixels, SD = 3.36), than non-deviating phases (M = -3.55 pixels, SD = 5.93).

Furthermore, with Mauchly's test of sphericity not violated X^2 (2) = 3.35, *p* = 0.17, a near significant main effect of workload was also observed, *F*(5,110) = 2.15, *p* = 0.06, η_p^2 = 0.09, power = 0.69. Bonferroni corrected pairwise comparisons however revealed no significant effects, all *ps* > 0.05. Interactions between AOSPAN and phase, AOSPAN and workload, and AOSPAN, phase, and workload were all non-significant; *F*s < 0.6 and *ps* > 0.7, as was the between subjects factor of

AOSPAN group, $F(1,22) = 1.64$, $p = 0.21$ (see Figure 4.3 for differences of spatial gain across working memory capacity).

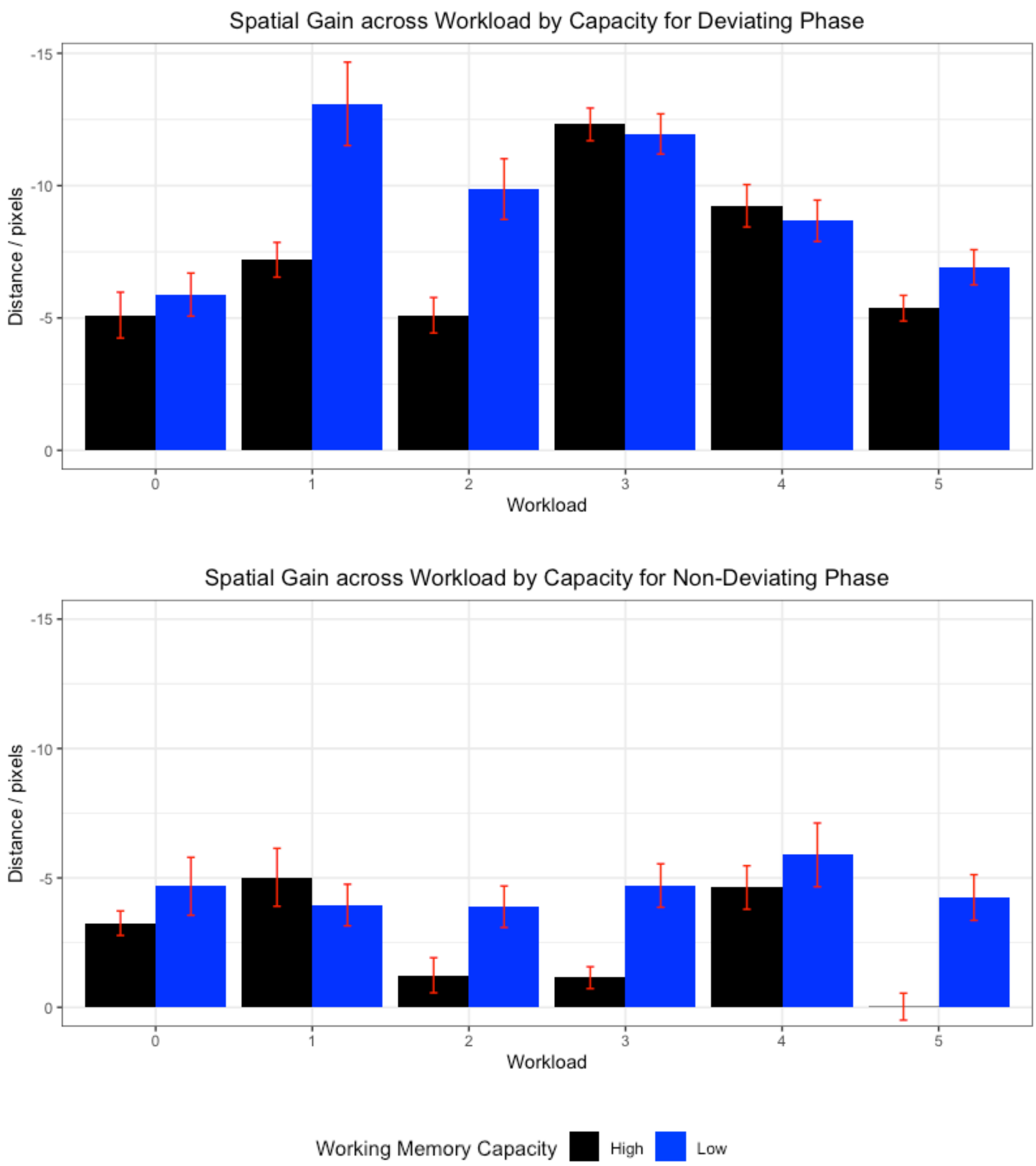


Figure 4.3. Top: Spatial gain across workload for deviating phases, separated by working memory capacity group. Bottom: The same but for non-deviating phases, bars represent the standard error of the mean for both, and negative is plotted upwards on the y axis for both.

4.1.4 Discussion

In summary, Study 4.1 attempted to investigate whether a reliance on motion information was dependent on working memory capacity when tracking targets in a novel tracking paradigm. Results from the analysis showed a main effect of phase, whereby participants lost more distance from the tracked target when it deviated unpredictably compared to when trajectories were predictable (no deviations). Furthermore, no effects interacted with working memory capacity, suggested that the main effect of phase was not dependent on resources but instead encompassed all participants. This suggests that there is therefore a reliance on motion information by participants when tracking the solitary target, and that is not dependent on the amount of resources that can be allocated to the task. Whilst an approaching significant effect of workload was observed, observation of the trend when plotted revealed no real patterns.

The main finding of the study is that participants lose more distance to the target square in unpredictable phases compared to predictable. Whilst this is similar to research that has looked at deviating trajectories in tracking under free viewing conditions (Howe & Holcombe, 2012), this was done so in a novel dual-task paradigm. However, actual distance lost across phases was fairly small, and no differences were found across groups. This could be suggestive of a flexible difference in approach to the task, where strategies such as covert and overt attention may be used simultaneously (Frielink-Loing, Koning, & van Lier, 2017), or where there is trade-off in quality and quantity in visual tracking (Fougnie, Cormiea, Kanabar, & Alvarez, 2016).

However, what may instead be a confounding factor is the dependent measurement taken here. Previous research looking at trajectory tracking has been in the form of a MOT task (Pylyshyn & Storm, 1988), where accuracy is taken in the form of a mark-all or probe-one procedure. The spatial gain measure taken here may be subject to a confounding factor when certain trajectories occur, for instance when the target deviates upwards from a diagonal trajectory. In such a deviation, spatial distance may momentarily decrease even though the correct path was followed, although the main effect of phase suggests that this small confound was averaged out. Taking this into account, a dependent measure that compares the position of the cursor square to the position of where the target square would have been in that moment would provide a measure that is not influenced by the same confound.

Another parameter of the study that may help to explain results would be the lack of eye fixation control, where in the current study participants could saccade to various points on the display, aiding the extrapolation mechanism. This reliance on motion information has been isolated in paradigms where eye movements are unrestricted (Howe & Holcombe, 2012), albeit only observable under lighter loads (Howe & Holcombe, 2012; Fencsik et al., 2007). The need to restrict eye movements when investigating reliance on motion information when tracking is furthered by research suggesting that smooth pursuit is required in order to estimate velocities in order to predict future locations (Zhong et al., 2014), which can occur only when eye movements are unrestricted. It may then be the case that participants use extrapolation as a strategy when possible in the current study, as eye movements are unrestricted, to compensate for a lack of ability to perform the task effectively.

The effect of allowing free saccades may in turn allow for other strategies that have been previously established, for instance, focusing on a central point that encompasses up to three objects to monitor movement (Fehd & Seiffert, 2008; Zelinksy & Neider, 2008), which as a strategy aids accuracy (Fehd & Seiffert, 2010).

Furthermore, rescue saccades can also be made to ensure targets are not lost when tracking (Zelinksy & Todor, 2010). These rescue saccades may therefore be the driving force of any potential confounding factor, if the lower working memory capacity group could not sufficiently allocate resources to track as effectively, then using rescue saccades more often would help with performance of tracking. This has also been proposed of extrapolation, that it is used as a recovery strategy and not directly for tracking (St. Clair et al., 2010).

Therefore, on the back of the results observed here in Study 4.1, and research isolating the role of eye movements in factors such as rescue saccades, the following study will introduce a fixation cross whilst tracking occurs. Whilst the fixation cross can only encourage central fixation and not enforce it, the presence of the stimulus will help to reduce saccades that may be influencing tracking mechanisms. The following study will also introduce two further changes to improve experimental validity: firstly, a new dependent measure will be computed to acquire a real-time measurement of how efficient tracking is, and secondly, deviation phases will be separated by trials in order to eliminate any roll-over effects. Lastly, linear mixed effects modelling will be used in order to investigate individual differences along the working memory capacity spectrum, instead of artificially creating two capacity groups and comparing across them.

4.2 Motion Information across Working Memory Capacity in a Novel Tracking Task: Central Fixations.

4.2.1 Introduction

Research Question

The following study aims to investigate whether working memory capacity differences drive differences in a reliance on motion information when tracking targets. Specifically, whether individuals that possess lower working memory capacity scores do not use motion information to predict target trajectories (proactive) and instead rely on reactive measures of tracking. The current study largely replicates Study 4.1; however, a number of methodological and analytical improvements are introduced in order to better isolate whether differences in tracking approaches are present.

Tracking with Eye Fixations

The key amendment made from Study 4.1 is the introduction of a central fixation cross, in order to encourage participants to fixate centrally whilst tracking. Whilst the absence of eye-tracking hardware does mean that there is no guarantee of fixations remaining central, the introduction of a fixation cross with instructions to not saccade will help to emulate the inattentional blindness screening paradigm used earlier in the thesis. Furthermore, research that has attempted to control for eye fixations has found that extrapolation through the use of motion information still occurs under light target loads (Luu & Howe, 2015), however it yet to be investigated whether this pattern encompasses participants with varying levels of working memory capacity. The introduction of a central fixation cross will also help to reduce a number of potential confounding factors identified in Study 4.1, the first of which being a potential tendency to track a number of targets by focusing on an imaginary central point and creating a centroid-like target (Fehd & Seiffert, 2008; 2010; Zelinksy & Neider, 2008).

The creation of this centroid-like target therefore allows participants to track a number of targets through estimating target positions when grouped together. The controlling of such a strategy is therefore important as both paradigms (Study 4.1 and 4.2) aim to assess to use of motion information to predict target trajectories. Whilst this strategy may fall into the broad theme of a compensatory mechanism, potentially used by participants with lower working memory capacity, the studies in this chapter explicitly aim to address the motion versus location information debate amidst working memory capacity. Controlling for saccades also helps to reduce the tendency for participants to make 'rescue saccades', whereby when a participant is failing to track targets, saccades can be made to the target to update location information in an emergency manner (Zelinksy & Todor, 2010). Again, whilst this does potentially fit into a compensatory like mechanisms that may be used by lower working memory capacity individuals, it does not fit in explicitly with the aims of the study.

The introduction of a central eye fixation cross will also contribute to the debate of whether extrapolations of targets through the use of motion information can be used in covert attention. Whilst some research has suggested that location information is the default input for tracking targets (Keane & Pylyshyn, 2006; Vul et al., 2009; Zhong et al., 2014), opposing research has argued that the usage of motion information in order to predict target positions is a utilised mechanism when required (Fencsik et al., 2007; Horowitz et al., 2006; Iordanescu et al., 2009; St. Clair et al., 2010). While there is debate over the mechanism, application to the real-world does also suggest that prediction must be used outside of fixation in order to estimate danger in situations such as driving. What the following study will explicitly address is whether the working memory capacity of the individual is a contributing factor as to whether motion information is utilised to predict target trajectories in a dynamic environment.

Linear Mixed Effects Modelling

Another of the changes that were made was the introduction of linear mixed effects modelling. Previous work in this thesis has separated participants into two groups, first by the nature of inattentional blindness, and then with capacity scores. This has been congruent with both previous research in inattentional blindness (Papera et al., 2014; Papera & Richards, 2016), with some MOT tasks (Drew & Vogel, 2008), and change detection tasks (Vogel et al., 2005). Although separating participants based on their inattentional blindness categorisation is fairly arbitrary, in the sense that the unexpected change is either observed or not, grouping participants based on capacity scores carries a number of flaws. Firstly, categorisation of capacity scores based on the mean score represents an artificial point as distributions are not naturally bimodal with working memory capacity. Furthermore, by averaging scores within the two groups, datapoints that cluster around the average are separated without having a robust difference, as means can differ when participants are recruited for further studies.

Therefore, linear mixed effects modelling was employed in order to keep the working memory capacity scores as a continuous variable, whilst maintaining the ability to manipulate variables such as target load. The move would allow for a regression model to account for dependencies among related data points by including random effects parameters. These random effects parameters essentially act as offsets for the regression model, thus, controlling for the variation caused by the levels of a random effects grouping factor, in this case the participant. Orthogonal contrast coding was used in order to be able to interpret both higher and lower order effects, as dummy coding (treatment contrasts) causes lower order effects to be replaced by simple effects, where they are estimated at the level of the of the baseline and not the grand mean.

In order to convene with standard statistical inference output, p values were obtained through the *lmer test* function in R (Kuznetsova, Brockhoff, & Christensen, 2017). Here the degrees of freedom and p values are calculated by using the Satterthwaite's (1946) method of approximation, whereas without this approximation inference is encouraged through the comparison of a null model to the model with an effects structure. This has been the case due to the level of dependencies within the random effects grouping factor (Singmann & Kellen, 2019), which stops the usual counting of degrees of freedom via the number of data points. The Satterthwaite approximation provides an acceptable level of Type I error control, as opposed to the alternative approach of comparing the t-statistic to the z distribution (Baayen, 2008).

Lastly, as model running was conducted through the R package *lme4* (Bates, Mächler, Bolker, & Walker, 2014), estimates of power were conducted through Monte Carlo simulations. Although other methods have been established in estimating power (see Westfall, Judd, & Kenny, 2014), models are often restricted in how many fixed effects can be included in the model. Due to the complexity of the model used in the current analysis, the *simr* package (Green & Macleod, 2015) in R was used in order to estimate observed power of significant effects and interactions in the model. The process of computing observed power consisted of three steps: firstly, a new dataset was simulated using the fitted model, the model is then refitted to the simulated data, and lastly, tested against the simulated data. The three steps were repeated 1000 times in order to compute a final power estimate. Although values were observed power estimates, effect sizes were not taken from the analysis, as this can yield inflated power estimates (Hoeing & Heisey, 2001). Furthermore, there is currently not a firm consensus on calculating effect sizes for complex linear effects models such as those used in this thesis (see Brysbaert & Stevens, 2018; Singmann & Kellen, 2019). Therefore, results are considering with associated p values, power, and correlations across the tested capacity spectrum. For power estimates, effect size estimates were guided by relevant object tracking literature (Flombaum et al., 2008: Lu & Howe, 2015; Meyerhoff et al., 2013), as opposed to independently using benchmarks outlined in Cohen's (1988) work, as it did not consider repeated measures variables (Lakens, 2013).

Rationale

The rationale for the current study consequently overlaps greatly with the rationale of Study 4.1, but with the additional parameters that have attempted to both make the paradigm more robust to isolating tracking differences and the analysis more sensitive to individual differences. The tracking task therefore maintains the dual-task nature, to keep similarities to the inattentional blindness screening paradigm, and the unpredictable movement of the target square will help to isolate a reliance on motion information. If differences do emerge across working memory capacity, specifically, if lower working memory capacity individuals exhibit better tracking on unpredictable trials due to a tracking strategy that relies only on location information because of capacity restraints, results would have implications for inattentional blindness and visual tracking research.

Hypotheses

The hypotheses will be stated in order that foreshadow the analyses: in regard to accuracy there are no a priori hypotheses made, as the dual task requirement was included in order to maintain a similarity to the inattentional blindness screening task (Chapter 2). In regard to the new dependent measure, the percentage of time spent outside the tracking threshold (see *Tracking Task – Factors* for a detailed explanation), it is hypothesised that lower working memory capacity participants will spend more time outside the tracking threshold for non-deviating trials compared to higher working memory capacity participants.

However, the reverse pattern is hypothesised for deviating trials, whereby if higher working memory capacity participants are using motion information to predict trajectories, when the target deviates unpredictably, they will exhibit less efficient tracking (higher percentage of time outside tracking threshold) than lower working memory capacity participants. Lastly, an exploratory analysis was conducted in the number of tracking shortcuts taken whilst tracking, as participants were told to explicitly follow the pathway of the target square, a high number of shortcuts would represent task instructions not being followed.

4.2.2 Methods

Participants

A total of 27 participants were recruited using a cloud-based participant management software. All had normal or corrected to normal vision and were naïve to the experimental hypotheses. All experimental procedures were approved by the Birkbeck research ethics committee, and informed consent was taken before testing. Participants were excluded due to not reaching the reaction time threshold on the AOSPAN task (one participant excluded). The remaining 26 participants were aged between 22 – 45 (M = 28 years, SD = 10).

Tracking Task - Stimuli

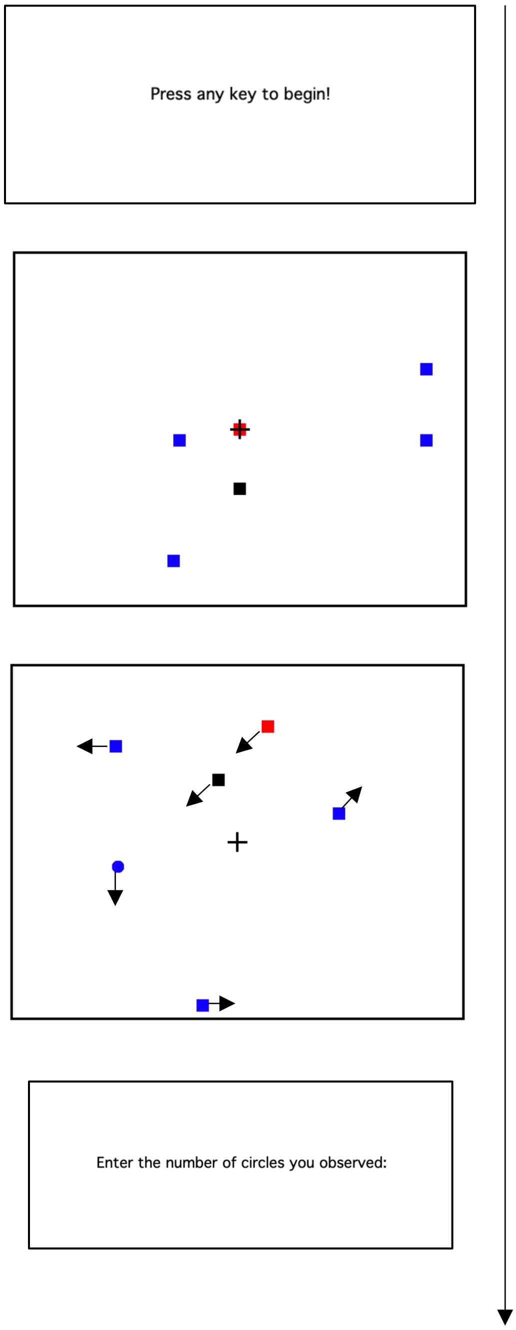
The tracking task was also developed using Matlab (Mathworks) and the Psychtoolbox extension (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). The monitor used was a Samsung SyncMaster 2233, with display measurements of 1920 x 1080, with a viewing distance of 60cm. The task consisted of three types of stimuli denoted by colour; a red cursor square controlled by the participant, a black target square, and blue distractor squares. Each square was identical in size; subtending 1.1° of visual angle, all squares moved at a rate of 2.6°/s, rebounding off the boundary but not off other squares. The restricted boundary in which stimuli were shown subtended 15 x 15° of visual angle. The random deviations of the black target square were computed by the substituting of coordinates that would produce a random change in a horizontal, vertical, or diagonal fashion, but with velocity kept constant.

Tracking Task - Procedure

The tracking task had two practice sessions, to begin with, participants were shown the red cursor square with no other stimuli. Participants were instructed to practice moving the red cursor square with the keyboard controls; arrow keys for regular movement and the keys ‘q’, ‘w’, ‘a’, and ‘s’ for diagonal movements – this session was untimed and was ended when the participant felt comfortable with the controls. This initial session was followed by another practice session, where 10 trials were completed, these trials were identical to the main experimental trials. The experimental trials lasted 20 seconds and began with a screen prompt which the participant had to trigger in order to begin the trial. Stimuli were presented on screen, with the red cursor square always presented centrally on the central fixation cross and black target square presented at a maximum of 2° apart. The blue distractors squares, if present on the trial, would be distributed randomly.

Movement of the black target square and blue distractor squares (if present) occurred immediately and in a random linear fashion, with rebounds occurring off the boundary edge but not off other squares. Whereas in Study 4.1 deviations would occur in every trial, here trials included deviations or did not. In deviation trials the black target square would randomly deviate three times, distributed randomly within the trial, with each deviation separated by at least 1000ms so that two deviations did not amalgamate. The number of blue distractor squares varied from none, to two, to four, and could randomly change into a blue circle for 1000ms before changing back, these square-to-circle changes could vary from none to eight within one trial. At the end of the 20 second trial a screen prompt was shown asking participants how many blue square-to-circle changes they observed (see Figure 4.4 for example trial sequence).

Prior to the task, participants were instructed to follow the pathway of the target black square as accurately as they could through movement of the red cursor square whilst maintaining fixation on the central fixation cross. They were asked to simultaneously monitor the blue distractor squares, and to observe any square-to-circle changes. Participants were told that three deviations in the trajectory of the black target square would occur in certain trials, in addition to the number of potential blue distractor squares present and the number of potential square-to-circle changes. Participants completed a total of 60 trials, separated into blocks of 20.



Trial trigger prompt (until user response).

Example stimuli layout for beginning of trial, red cursor square placed centrally on fixation cross.

Main phase of trial with four distractor squares, arrows denote movement, with example square-to-circle change shown (20s).

Probe (until user response).

Figure 4.4. Trial sequence for the tracking paradigm, with two images from the tracking period.

Tracking Task – Factors

Two independent variables were present in the tracking task; trial nature, with the black target square either eliciting unpredictable deviations or not (occurring across trials), and distractor square load, either no distractors, two, or four. A measure of accuracy was taken on the square-to-circle changes, measured through the end of trial probe. Furthermore, an updated measure of tracking performance was computed, the percentage outside threshold (POT), here the location of the red cursor square was compared to the location of where the black target square would have been in that instance. Thus, providing a real-time measure of how far the red cursor square was from the pathway of the target square, measurements of difference were taken on average 58 times a second. This was used instead of an indication of positional accuracy to the target itself, as due to the unpredictable deviations, the participant might find themselves in a position close to accuracy through coincidence, regardless of pathway tracking ability.

A threshold value of 25 pixels was afforded as the boundary for the red cursor square to be within, as although participants were told to explicitly follow the pathway of the target square, an allowance for a deviation of 25 pixels from the central point of the pathway was considered passable as correct tracking. A measure of the number of shortcuts taken by the participant was also computed, as both the black target square and the red cursor square moved at the same speed, a reduction in distance between the cursor square and the matched pathway location would constitute a shortcut. A threshold was set of a minimum of a 50-pixel movement, to ensure that mistaken key presses were excluded in the measurement, the total number of shortcuts were tallied across conditions. The threshold of 50-pixels was also used to separate instances where shortcuts were close together.

Tracking Task – Relevance

The main aim of the tracking task introduced here was identical to Study 4.1, the changes made to the study include the fixation cross and consequent restricted boundary. The fixation cross was introduced in order to encourage a central fixation, as the use of motion information with central eye fixation has been established (Luu & Howe, 2015), and that covert attention tends to be anticipatory in nature (Frielink-Loing et al., 2017). Furthermore, a central fixation will help to restrict the confounding factor of participants potentially fixating strategically to track a number of objects (Fehd & Seiffert, 2008, 2010; Zelinksy & Neider, 2008). The restricted boundary was therefore introduced in order to keep all stimuli within comfortable peripheral vision.

One concern from Study 4.1 were potential roll-on effects from having deviating and non-deviating phases in the same trial, where performance in a deviating phase then effects the measurement in the non-deviating phase immediately after. Therefore, the change to separating the deviation across trials aimed to help eliminate this confound. The purpose of changing the distractor square workload was to simplify the analysis and reduce the number of levels in that variable, given that analysis from Study 4.1 did not present evidence of changes across the existing levels. Lastly, the change in measurement was to isolate clearer tracking patterns, as the previous measurement of spatial gain may have been confounded by target square deviations that bring the target and cursor squares temporarily closer together.

AOSPAN Task – Stimuli and Procedure

The AOSPAN was identical to previous versions used in this thesis and has been described in Study 2.2.

AOSPAN Task - Factors and Relevance

The AOSPAN task factors and relevance remained the same as in Study 2.2.

4.2.3 Results

Accuracy

Accuracy of detecting the square-to-circle changes was found to be heavily influenced by distractor workload, floor effects were found for accuracy rates when separated by the level of distractor squares, no distractors (M = 100%, SD = 0), two distractors (M = 0%, SD = 0), and four distractors (M = 0%, SD = 0).

Percentage Outside Threshold (POT)

The POT score was entered into a mixed effects model, with AOSPAN score, distractor load, and trial nature as the predictor variables, orthogonal contrasts were used for categorical variables in every case the participant was entered into the model as a random effect. Bivariate correlations were then run to assess any interactions, and pairwise comparisons using the *lsmeans* function for the main effects, where error was adjusting through the Tukey approach. Power estimates were computed through Monte Carlo simulations through the *simr* package (Green & Macleod, 2015), effect sizes for the main effects were estimated at 0.4 and at 0.1 for interactions and were run for significant terms.

A main effect was observed for distractor workload, $F(1,25) = 7.56$, $p < 0.01$, power = 0.10, with four distractors (M = 78.29%, SD = 13.51) significantly differing from trials with no distractors (M = 75.59%, SD = 16.91), $t(25) = 2.98$, $p = < 0.01$. Trials with two distractors (M = 77.26%, SD = 13.86) also approached significance when compared to the no distractor workload trials, $t(25) = 1.87$, $p = 0.06$. A main effect for trial nature was also observed, $F(1,25) = 11.65$, $p < 0.01$, power = 0.05, across non-deviating trials (M = 76.03%, SD = 16.62) and deviating trials (M = 78.12%, SD = 12.71, Figure 4.5).

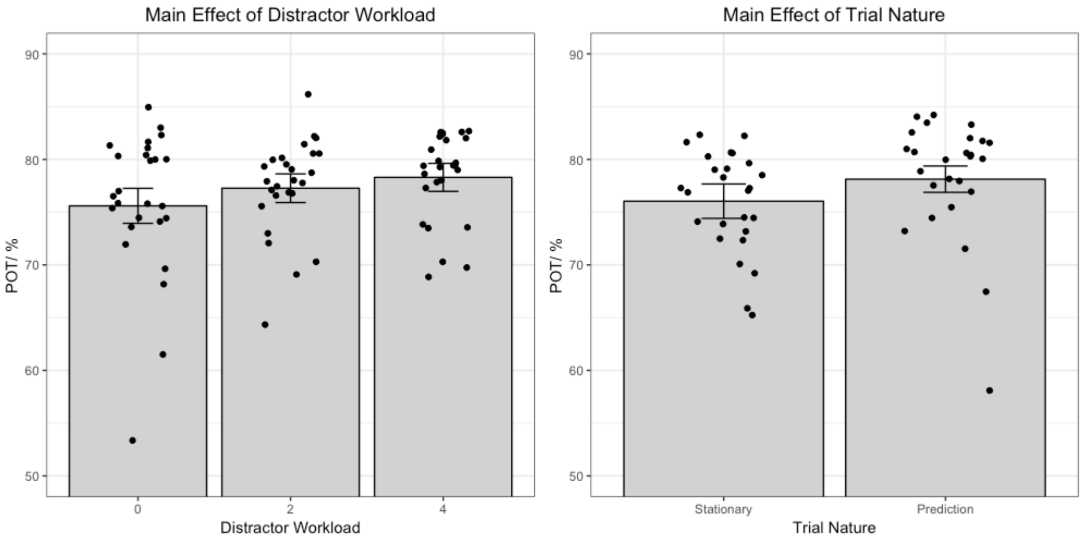


Figure 4.5. Left: Main effect of distractor workload. Right: Main effect of trial nature, bars represent standard error of the mean for both.

The analysis also revealed two interactions, a significant interaction between AOSPAN score and distractor workload, $F(1,25) = 3.06$, $p = 0.01$, power = 0.16. Here bivariate correlations revealed a near significant correlation for no load trials, r = 0.38, $p = 0.05$, but not for either two or four distractor trials, r = 0.22, $p = 0.26$ and r = 0.20, $p = 0.33$. Additionally, a near significant interaction between AOSPAN score and trial nature, $F(1,25) = 3.82$, $p = 0.05$, power = 0.54, here bivariate correlations revealed a significant correlation between AOSPAN scores and POT in non-deviating trials, r = 0.49, $p = 0.02$, but not deviating trials, r = 0.14, $p = 0.47$ (Figure 4.6).

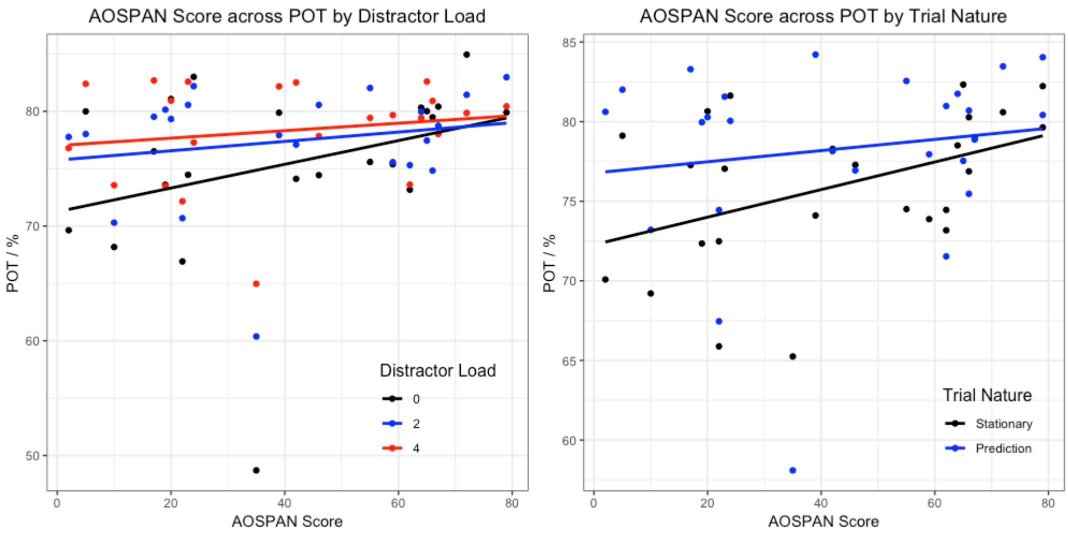


Figure 4.6. Left: Scatterplot of POT scores across levels of working memory score separated by distractor load. Right: Scatterplot of POT scores across levels of working memory separated by trial nature.

The POT measure was used in order to assess overt tracking efficiency, and while differences were found across levels of working memory capacity, the binary nature of the measure does have room for improvement. Therefore, the POT measure was broken down into five levels of increasing distance: under 50 pixels, under 75 pixels, under 100 pixels, under 125 pixels, and lastly over 125 pixels. A POT measure was obtained for each level and was entered into a separate model with the same fixed and random effects as previously. The only significant predictor for to what degree participants diverged from the correct tracking position was the nature of the trial (non-deviating or deviating), see Table 4.1 for results. All other main effects and interactions were non-significant, $p > 0.05$.

Table 4.1. Coefficients for the main effect of trial nature for each distance grouping, ** denotes significance to 0.01, * denotes significance to 0.05.

Distance	*df*	*F value*	*P value*	*Mean POT/SD*
Under 50 pixels	1,25	10.16	< 0.01**	Non-deviating = 13.52%/24.41 Deviating = 8.39%/15.97
Under 75 pixels	1,25	4.94	0.03*	Non-deviating = 11.10%/17.24 Deviating = 7.28%/10.71
Under 100 pixels	1,25	2.87	0.09	Non-deviating = 11.21%/16.07 Deviating = 8.30%/11.02
Under 125 pixels	1,25	3.04	0.08	Non-deviating = 8.99%/13.45 Deviating = 7.26%/9.32
Over 125 pixels	1,25	30.48	< 0.01**	Non-deviating = 53.25%/35.66 Deviating = 68.74%/27.58

The last measurement from the dataset was aimed to isolate the number of shortcuts taken by participants. A main effect of distractor load was observed as approaching significance, $F(1,25) = 2.52$, $p = 0.08$, however, no significant differences were found across the levels: no distractors (M = 6.81, SD = 5.45), two distractors (M = 6.71, SD = 6.66), and four distractors (M = 6.94, SD = 5.29), all ts < 0.4, all ps > 0.5. An interaction between distractor load and working memory capacity was approaching significance, $F(1,25) = 2.79$, p = 0.06 (Figure 4.7). However, bivariate correlations revealed no associations between working memory capacity and the number of shortcuts in any level of distractor load, no distractors r = 0.14, $p = 0.49$, two distractors r = 0.28, $p = 0.17$, and four distractors r = 0.06, p = 0.76.

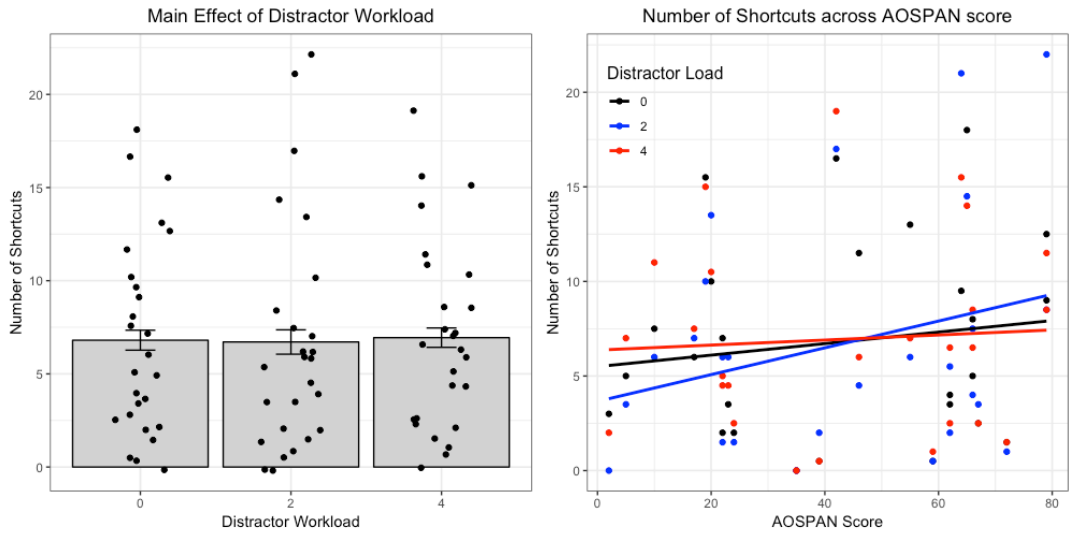


Figure 4.7. Left: Main effect distractor workload on the number of shortcuts, bars represent standard error of the mean, and points represent individual data points. Right: Interaction between AOSPAN score and distractor load on the number of shortcuts.

4.2.4 Discussion

In summary, this study attempted to investigate whether differences in working memory capacity contributed to the tendency to use either location or motion information when tracking targets in a novel tracking paradigm. Work was built upon results in Study 4.1, with a number of amendments made to both the paradigm used and the analysis technique employed. Accuracy rates for detecting the circle-to-square changes was observed at floor levels, with no registered accurate responses for trials with distractors. Whilst this result does suggest a difficulty level that is beyond demand, the aims of the study was to investigate whether differences emerge in the strategy for tracking. Therefore, whilst floor effects in the secondary square-to-circle task is not ideal, divergent strategy use to tracking may still be evident, such as when task demands in tracking are not met in MOT (Drew & Vogel, 2008).

Analysis into the POT variable revealed main effects of distractor workload, with a significantly higher percentage of time being spent outside the tracking threshold for four distractors compared to none, with an approaching significant difference between two distractors and none. Therefore, whilst accuracy in determining the square-to-circle substitutions did not differ, the effect of loading demand on the variable did influence the POT for participants. A main effect of trial nature was also observed to show a significant difference, with a higher POT for deviating trials compared to non-deviating, reflecting research showing a detrimental effect of unpredictable trajectories to target tracking (Luu & Howe, 2015). The result also suggests a reliance on motion information when tracking the single target, as tracking efficiency showed greater loss when target trajectories were unpredictable.

Analysis into the POT also revealed two interactions with working memory capacity, the first with distractor load, where a significant positive correlation was observed between working memory capacity and no-load trials. The second, between working memory capacity and trial nature, with a positive correlation being observed between capacity scores and non-deviating trials. Both correlations suggest that under light loads, and when target trajectories are predictable, individuals with lower working memory capacity spend less time outside the tracking threshold. This novel finding opposes original hypotheses for the study, as it was predicted that individuals with higher working memory capacity would exhibit greater tracking efficiency under predictable trajectories, and inferior tracking under unpredictable due to a reliance on motion information.

An exploratory analysis was also conducted to observe whether the number of overt shortcuts taken was dependent on working memory capacity, however, no differences emerged across capacity scores. One main implication to consider, and that may help to explain the superior tracking performance of lower working memory capacity individuals is the nature of the dependent variable when compared to traditional performance measures. In the current study, tracking performance is measured not through the ability to answer a probe at the end of a trial, like in MOT tasks, but instead the efficiency of tracking a single target throughout. Therefore, the correlations may be suggestive that a stricter tracking strategy may have been employed by participants who have lower working memory capacity, which can consequently only be done at lighter cognitive loads. This ability to adhere to a stricter tracking strategy was then extinguished under higher demands, due to a lack of resources. Given the lack of interactions with accuracy, results do suggest that the strictness in tracking pattern did not influence the secondary square-to-circle task. There is therefore a tentative suggestion for divergent tracking strategies across working memory capacity, which in turn may go undetected if only assessing accuracy at the end of a trial.

The result identified is also considered tentative due to the nature of controlling for saccades, specifically, when using a behavioural fixation cross and no eye tracking, there is not a strong guarantee for central fixation. Therefore, results of the current study cannot strongly contribute to mechanisms of overt or covert attention, however, results do suggest that differences across working memory capacity are evident. There are consequently implications for previous research conducted in this thesis in regard to the inattentional blindness paradigm, surrounding literature for the usage of motion information when tracking targets, and methodological implications for the use of linear mixed effects modelling when investigating working memory capacity.

4.3 General Discussion

In the current chapter, two studies were presented that attempted to investigate the role of working memory capacity in tracking targets, and whether there was a divergence in the reliance on motion information in a tracking task. Study 4.1 introduced a novel tracking paradigm, whereby participants had to track a target square whilst monitoring potential changes in other visual stimuli. A reliance on motion information was tested through unpredictable deviations of the target square, where greater distance lost in such periods reflected a greater reliance on motion information. Results suggested a participant wide reliance on motion information, that was not determined by working memory capacity. However, upon evaluation of the paradigm and dependent measure a number of amendments were introduced, namely, a central fixation cross, a new dependent variable that measured real-time accuracy to the pathway of the target, and linear mixed effect modelling to eliminate the artificial grouping of participants.

These changes were implemented in Study 4.2, where both the load of visual stimuli and the nature of the trajectory of the target influenced how efficient tracking was. More importantly, however, working memory capacity interacted with both the load of trials and trajectory nature. Bivariate correlations revealed that individuals with lower working memory capacity produced a more stricter tracking patter under lighter loads and when target trajectories were predictable. Interactions did oppose initial hypotheses, which proposed that participants with greater working memory capacity would elicit superior tracking under predictable trajectories, due to an increased ability to predict. However, conclusions were made to suggest that the dependent measure may not have directly measured tracking efficiency, but more so a strictness in tracking strategy.

If taken from such a perspective, then results would suggest that when able to, specifically, when target trajectories do not deviate unpredictably and when no distractors are present, individuals with lower working memory capacity employ a stricter, more intense pattern to tracking. This pattern then attenuates when load increases, or when motion information becomes unreliable (unpredictable trials). What is also important to note, is that whilst there was a divergence in tracking pattern based on working memory capacity, no such divergence was present in behavioural accuracy of the task. Suggesting that a number of pathways were applicable to achieve the same behavioural result. This then becomes a point for future research, as divergent strategies were observed on the behavioural level, with further scope to investigate whether divergence is present on the neural level.

The notion of lower working memory capacity individuals having to work harder in order to achieve comparable results is mirrored with some neural experiments. Vogel and colleagues (2005) observed inefficient inhibition of distractors in a change detection task by lower working memory capacity individuals. Such individuals elicited a tendency to process more stimuli than what was required, whereas participants with higher working memory capacity illustrated a more efficient strategy by processing only targets and inhibiting distractors. Results in the current chapter therefore show similarities to such work and carry implications for real-world situations. If it is the case the lower working memory capacity individuals employ different, but more cognitively demanding, strategies to tasks such as tracking, this may have an end results on prolonged activities such as driving or in professional vigilance tasks (air traffic control).

It may therefore be the case that although differences in behavioural results do not emerge over the course of a study, like here in Study 4.2, over prolonged activities, such as long drives or monitoring of aviation pathways, inferior performance by lower working memory capacity individuals may start to emerge. This therefore has implications for research looking into specific working memory testing and training, as it may not directly be the case that inferior capacity means inferior performance, but that inferior capacity leads to a tendency to implement inefficient strategies. The results also carry implications for the theoretical background of tracking visual stimuli, which will be discussed now.

Theoretical Implications

A number of theories have been proposed to explain findings in tracking, specifically multiple object tracking, and whilst in the current chapter tracking comprised of a single target and a controllable cursor square, attention was still required to be shared across the number distractors across the display. Results here conflict with the early theoretical accounts of MOT, namely that there is not a fixed architecture to tracking (see FINST theory, Pylyshyn, 1989; Pylyshyn, 2001). Instead, results suggest there is flexibility in the approach to tracking that is dependent on working memory capacity. Results are therefore more in line with models that propose a flexible approach to object tracking (Alvarez & Franconeri, 2007), where research has shown through changing tracking parameters resources can be completely allocated at a different number of points.

This is in line with research discussed previously (see Drew & Vogel, 2008; Holcombe & Chen, 2012; Iordenescu et al., 2009). Whilst research has shown differing performance based on direct tracking performance (Drew and Vogel, 2008), differences have also been found across working memory capacity in restricting irrelevant objects from consuming capacity (Vogel et al., 2005). Here individuals with lower working memory capacity were found to store more items than required, which may help to explain the trend seen in Study 4.2.

In regard to the multifocal theory of attention, with the suggestion that multiple foci of attention allow for a continuous monitoring of objects during a trial (Cavanagh & Alvarez, 2005). The theory has strong support, such as evidence for separate resource allocation for independent hemifields (Störmer, Alvarez, & Cavanagh, 2014), or through the generation of separate foci of attention for new visual objects (Eimer & Grubert, 2014). Here the below chance level of performance in the circle substitution task suggests that whilst attention could have been split across the display, the demand for tracking the target square was taxing to the degree that performance was greatly impaired. It is therefore more a consequence of the difficultly of the tracking task that differences are not seen in the secondary circle substitution task.

Implications for Inattentional Blindness

The difference in approach to the task has implications for previous work in this thesis. It is suggestive that there is not just a single method to an outcome, which is pertinent given that in an inattentional blindness task, participants are then classified on a single trial outcome. Research into the dual route model of inattentional blindness (Richards et al., 2014) has suggested that capacity may be a determining factor in the propensity to miss items in a visual display. Items may not just be missed due to a lack of processing capacity (low working memory capacity), but individuals with a higher capacity may inhibit irrelevant objects and consequently not perceive them as a result.

Although links between working memory capacity and inattentional blindness are inconclusive (see Beanland & Chan, 2016; Hannon & Richards, 2010; Richards et al., 2010), results here suggest that individuals with lower working memory capacity may employ strategies that consume more capacity when available. This inefficient deployment of resources would mean lower working memory capacity individuals would carry a higher tendency to miss other objects in their visual field. Given that inattentional blindness has been linked to the inefficiency in the suppression of distractors (Papera & Richards, 2017), the stricter behavioural tracking pattern shown here may also be representative of an inefficient approach to the task.

Future Directions

The link between the inattentional blindness classification task and the multiple object tracking task (MOT) is not one that has been explored, however, the MOT paradigm does provide an established method of investigating whether behavioural outcomes are matched in similarity in neural approach. The contralateral delay activity has been established as a neural measure of the number of items held in visual working memory (Vogel & Machizawa, 2004; Tsubomi, Fukuda, Watanabe, & Vogel, 2013; Kuo, Stokes, & Nobre, 2012; Kang & Woodman, 2014; Li, He, Wang, Hu, & Guo, 2017) and later the number of items tracked in the MOT task (Drew et al., 2011; Drew et al., 2013; Drew et al., 2012; Drew & Vogel, 2008), with a greater amplitude for tracking compared to items held in working memory. The two concepts can therefore be married together to assess whether neural patterns show divergence across working memory capacity when tracking multiple objects.

Work in this chapter has established a degree of difference in working memory capacity and the approach to tracking and discussed implications for theories of inattentional blindness and object tracking. In the following chapter work will transition to investigating in more detail whether working memory capacity is a determining factor in how individuals perform when asked to track multiple targets. The work in the chapter will take advantage of being able to monitor both the behavioural performance of participants and the neural indexes of tracking to assess differences in strategies employed.

Chapter 5. Motion Information in a MOT Task across Working Memory Capacity: An EEG Study

5.1 Motion Information in MOT across Working Memory Capacity

5.1.1 Introduction

Research Question

The following study aims to investigate whether working memory capacity limitations drive differences in tracking strategies. Specifically, whether individuals that score lowly on capacity measures implement different tracking strategies that neurally diverge from high scoring participants, but ultimately reach similar behavioural accuracy rates. The following study will introduce a trial gap to the traditional multiple object tracking (MOT) paradigm to facilitate the requirement to predict trajectories of targets through comparison of the contralateral delay activity (CDA) component, and then assess whether working memory capacity drives the capability to do so under varying target loads.

Visual Tracking

The success of navigating through dynamic, everyday tasks is heavily dependent on the ability to attend to multiple objects in our visual field. Given the nature of our environment, it is often a requirement to store mental representations and predict future spatial positions based on previous information, such as when driving at busy junctions. This ability stems from the working memory domain; the ability to actively maintain visual information to serve the needs of ongoing demands. Work in the previous chapter attempted to isolate overt tracking differences across levels of working memory capacity, however, in the current chapter a move is made from the novel tracking paradigm to one that is already established in literature. The MOT task (Pylyshyn & Storm, 1988) has been used to investigate the ability to track a number of targets set amongst distractors. These targets are defined at the beginning of each trial, where then participants have to mentally maintain the identity of the targets and track the movement of them.

Performance in the MOT task has given rise to a number of theories that attempt to explain the approach to tracking multiple targets. Theoretical accounts have provided a number of explanations to the mechanisms to tracking, such as discrete, fixed visual indexes (FINST, Pylyshyn, 1989, 2001, 2007). However, the obvious drawbacks of proposing a mechanism that is automatic and not cognitively demanding but yet has to meet requirements of continuous spatial updating meant that a number of theories have come forth since. Mechanisms of tracking have also covered multifocal attention, where attention can be split over a number of targets (Cavanagh & Alvarez, 2005), and has found supportive evidence with attention being shown to operate in parallel for multiple targets (Jenkins et al., 2018). A flexible allocation of resources theory has also been put forward to explain tracking (Alvarez & Franconeri, 2007), supportive evidence has come from research such as Holcombe and Chen (2012), where a single target has been shown to completely exhaust tracking resources. This link to differing attentional deployment is also relevant for research that has investigated individual differences in the MOT task (Oksama & Hyömä, 2004) and the divergent neural signatures of good and bad trackers (Drew & Vogel, 2008).

Parametrical factors can therefore affect the accuracy of tracking by exhausting the resource pool of participants, factors such as the number of distractors (Bettencourt & Somers, 2009), the speed at which even a single target moves (Holcombe & Chen, 2012), the speed of multiple objects (Alvarez & Franconeri, 2007; Meyerhoff et al., 2016), the number of targets (Drew, Horowitz, & Vogel, 2013; Drew et al., 2011, Pylyshyn & Storm, 1988), and crowding of objects (Franconeri et al., 2010). It is therefore established that task demands can result in differing performances across participants, however research has yet to identify whether divergent tracking strategies are also in play, and more specifically whether they differ as a function of working memory capacity.

It is this flexible resource model that is most relevant to the research theme in this chapter, with investigations aiming to assess whether different neural signatures are evident across the spectrum of working memory capacity, as opposed to directly linked to tracking performance (Drew & Vogel, 2008). The differing neural signatures that were established across good and bad trackers were done so in 'supra-capacity' displays (Drew & Vogel, 2008), where the numbers of target exceeded the established 3-4 item limit (Cowan, 2001). Furthermore, the categorisation of good or bad tracking was done so through a tracking capacity term based on accuracy responses. Whilst differing neural signatures have been established at extreme loads across groups that either perform well or not, it has yet to be determined whether capacity resources, not performance itself, can give rise to similar accuracy outcomes through differing approaches to tracking.

One factor that has been investigated in the tracking of multiple objects and is linked to the hypothesis of this chapter is the role of predictive processing. A number of studies have looked at the role of extrapolation and prediction in tracking objects through the occlusion or disruption of tracking targets. Here longer occlusion periods result in lower tracking accuracy, in periods between 100-500ms (Horowitz, Birnkrant, Fencsik, Tran, & Wolfe, 2006), however, when objects were stationary under longer occlusion periods, of 900ms, performance did not deteriorate further

(Keane & Pylyshyn, 2006), suggesting it is the location shift that is the determining factor, not the time of occlusion, with larger shifts more detrimental to accuracy (Keane & Pylyshyn, 2006). Results therefore suggest that motion information may not be utilised in all tracking scenarios.

One criticism put forward is that a situation where a large number of targets disappear synchronously is unlikely in the natural world (Franoneri et al., 2012), with serial occlusion much more probable. The former point regarding target load has been found to have significance, with motion information being utilised under lighter loads (Ellner et al., 2012) and when object motion was fast (Luu & Howe, 2015). Evidence has also shown individuals are more likely to estimate the last known position of a target in its forward motion path than its backward window, even at a target load of three, which is near capacity limits (Iordanescu et al., 2009).

There is therefore an implication of predictive processing of target trajectories in tracking tasks, with the consequent demand such a process places on working memory resources. There are therefore also similarities to the demands in the inattentional blindness screening task, with predictive processing may being employed under lighter loads or with those individuals with greater resources to spare. At the very least, it can be said that the approach to tracking may diverge on the basis of working memory capacity (see Chapter 4), even if the change is not consistent across loads. The following study will investigate whether predictive processing in a tracking task is a strategy that is automatic and implemented by all participants, or whether the differences in working memory resources drive divergent approaches to tracking targets. Consequently, the role of the contralateral delay activity is integral to associating neural activity throughout the tracking process to behavioural accuracy. The following section will introduce the contralateral delay activity, with further information as to the cognitive mechanisms that it reflects.

Contralateral Delay Activity

The CDA is a slow wave negative component observed at posterior regions, usually most pronounced at the PO7/PO8 electrodes and is a component observed contralaterally to the participant's cued visual field. The terminology of the component originates from its first use as a measure of the number of items held in working memory during a retention interval between displays (Vogel & Machizawa, 2004). The component therefore carries an important implication in the regard that the amplitude is directly linked to the number of items held in visual working memory. Vogel, McCollough and Machizawa (2005) later found that CDA can also function as a measure of control of working memory that can account for individual differences; specifically, selection efficiency through a moment-by-moment basis.

The most established, putative characteristic of the CDA component is the relation of amplitude to the number of objects maintained in visual working memory, specifically its congruency with the 3-4 item limit (Cowan, 2001). More relatable to the aims of this study is research linking CDA amplitude to multiple object tracking. Work in the current chapter introduces a masking period in the multiple object tracking paradigm, where participants are required to either maintain stationary representations of targets or predict trajectories. The number of items tracked in the multiple object tracking task has been robustly linked to CDA amplitude, with its amplitude rising with the number of tracked items but importantly reaching a plateau when capacity limits are reached, with different neural signatures for participants with greater tracking capacity (Drew & Vogel, 2008).

Given that there is an established increase in amplitude for tracking targets compared to maintaining representations (Drew et al., 2011, see also Vogel & Machizawa, 2005; Vogel et al., 2005), the component can offer insight as to whether participants are simply maintaining representations over a trial gap to estimate locations, or actively tracking by predicting trajectories. This link is congruent with the attentional high-beam effect (Flombaum et al., 2008) whereby additional attentional resources are required to actively track items over a gap. Consequently, this approach would only be implemented by participants with resources to spare.

The CDA amplitude exhibited by participants is also sensitive to online changes within trials, with an increase in amplitude when participants are required to track an additional target (Drew et al., 2012). The distinction between attending to objects or having to track them in real-time was strengthened by amplitude differences in the CDA that correspond to a pause, a stop, or the continuation of movement in a MOT task (Drew et al., 2011). Interestingly, the authors note a delay in attenuation in CDA amplitude in pause conditions, which is suggested reflects a background predictive mechanism for tracking. While there is an argument to be made that this delay in attenuation of the amplitude might just reflect attention itself, and the after-effect of having to track targets.

The potential increase of CDA amplitude in a masking phase of the MOT task in this study would reinforce the idea that CDA amplitude is reflective of not only target representations, but an amalgamation of processes that reflect target tracking, specifically prediction of trajectories. Thus, the combination of an established paradigm such as the MOT with its robust link to the CDA will allow for a comparison of behavioural performance and neural pattern, where participants may implement varying approaches to achieve comparable behavioural performance.

Rationale

The rationale for the study was to investigate whether differences in neural activity reflect differences in strategy that ultimately results in comparable behavioural performance. Furthermore, whether these differences are driven by working memory capacity resources, whereby participants with fewer resources have to compensate for such a limitation through irregular tracking strategies. The conventional tracking pattern would involve a CDA amplitude matched with the number of items tracked, then an increase in amplitude when participants have to predict trajectories over a masking period, in line with an attentional high-beam effect.

However, a possible compensatory mechanism for those without the resources to actively track over a trial gap is to maintain the representations of targets where they were last observed and estimate target positions in a post-probe manner. This would become apparent through no increase of CDA amplitude across tracking and masking periods in prediction trials. The study also continued with the use of linear mixed effects modelling, the rationale for doing so was to not create artificial groups across the participants. Linear mixed effects modelling therefore allowed the manipulation of target load and trial nature whilst investigating differences across working memory capacity on a continuous scale. Furthermore, power estimates were obtained using the identical process used in Study 4.2, with effect sizes for main effects estimated at 0.4 and 0.1 for interactions (see Study 4.2: *Linear Mixed Effects Modelling,* for an explanation on power and effect sizes).

Hypotheses

The hypotheses will be formally stated in order that foreshadow the analyses; in regard to accuracy, main effects of accuracy were hypothesised, with higher accuracy rates on single target trials compared to three target trials. A main effect of trial nature was also hypothesised, with participants eliciting higher accuracy rates for stationary trials compared to prediction trials. It was hypothesised that accuracy scores would not differ as a function of working memory capacity, with instead divergent neural signals producing comparable behavioural performance.

In regard to the neural data, it is hypothesised that working memory capacity will drive differences in CDA amplitude. Specifically, participants with higher capacity scores will exhibit an increase in CDA congruent with target load: more negative amplitudes for three targets compared to one target trials. The higher capacity participants will also exhibit an increase in CDA for prediction masks compared to stationary masks, as they would actively track over the gap to predict trajectories. In comparison, lower capacity participants will also exhibit a CDA amplitude that increases with set size. However, in three target trials it is hypothesised that lower capacity individuals will not have the resources to actively track over prediction masks and therefore will not show the increased amplitude compared to stationary mask trials, which is hypothesised with high-capacity individuals (see Figure 5.1 for graphical representations of hypothesised amplitudes).

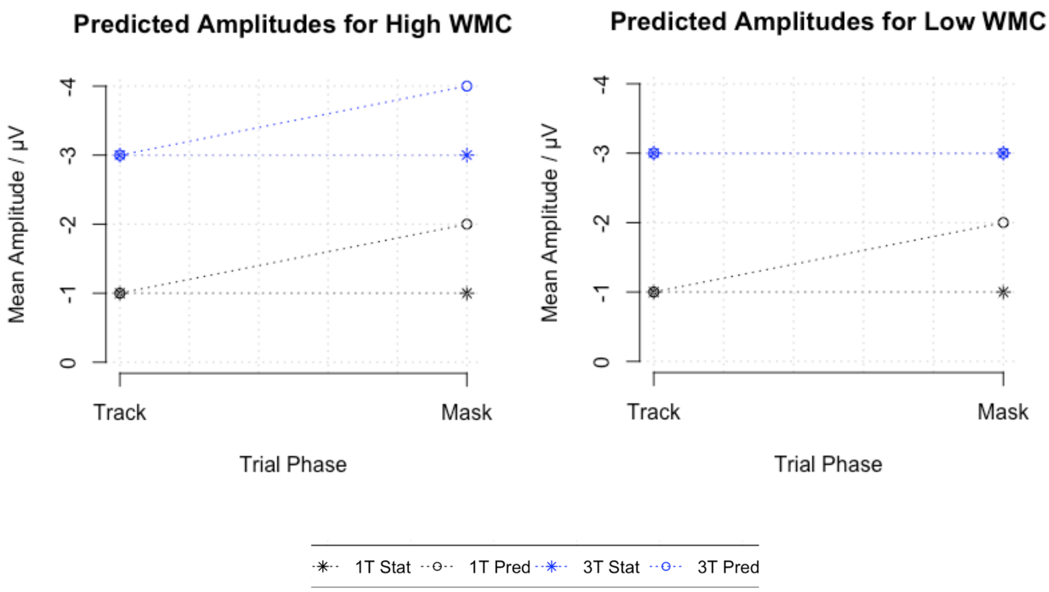


Figure 5.1. Left: Predicted amplitudes for high WMC participants, with the increase in prediction trials for both one and three targets from tracking to masking. Right: Predicted amplitudes for low WMC participants, with an increase in amplitude when predicting one target trajectories, but not with three targets. (Bottom) Legend denotes the number of targets (1T = one target, 3T = three targets), and trial nature (Pred = prediction, Stat = Stationary).

5.1.2 Methods

Participants

A total of 22 participants were recruited using a cloud-based participant management software. All had normal or corrected to normal vision and were naïve to the experimental hypotheses. All experimental procedures were approved by the Birkbeck research ethics committee, and informed consent was taken before testing. Participants were excluded due to noisy EEG data (two participants excluded), and for not reaching the reaction time threshold on the AOSPAN task (two further participants excluded). The remaining 18 participants were aged between 18 - 39 (M = 27 years, SD = 7; 10 women).

MOT Task - Stimuli

The MOT task was developed using Matlab (Mathworks) and the Psychtoolbox extension (Brainard, 1997; Pelli, 1997; Kleiner et al., 2007). The monitor used was a Samsung SyncMaster 2233, with display measurements of 1920 x 1080, with a viewing distance of 60cm. The MOT task was bilateral, with a MOT task running in each half of the screen (see also Drew et al., 2011; Drew & Vogel, 2008), with each half consisting of six objects. The bilateral MOT task has been used so that any difference in contralateral activity is due to the addition of process, for instance tracking. This is compared to only having a single MOT task on one side of the screen, where it would not be possible to separate tracking processes from pure sensory activity. The radii of the objects subtended to a visual angle of 3.34° and a frame width of 1.43°, all presented in regions subtending 6.20 x 6.20° per side. Velocities for x and y coordinates were randomly generated per trial with a maximum of 2.86°/s and a minimum of 0.28°/s for either axis. All objects occluded one another if trajectories crossed over, with all items bouncing only off the region boundary.

MOT Task - Procedure

A single trial began with instructions, dictating to the participant which side of the task the participant had to covertly attend to, and which mask would be applied, after which a fixation screen (100ms) would be presented. Thereafter the identification phase (1000ms) would present all objects without movement, with the targets consistently coloured red for the left MOT task, and blue for the right MOT task, with distractors coloured black. Next, the tracking phase (1000ms) would show all objects coloured black, with random linear movement from the starting positions.

Objects would occlude one another if they crossed and would randomly bounce off the region boundary. Lastly, the masking phase (1000ms) would cover all objects, excluding the fixation cross, with a white mask. The two variations of the mask were either stationary or prediction; under a stationary mask all objects would remain stationary from the last positions in the tracking phase. In a prediction mask, all objects would continue to move at the same velocity from the last positions from the tracking phase.

Finally, a random object was selected from the cued side, from its last position under the mask, and participants were asked whether this object was a target or not, pressing ‘y’ for yes or ‘n’ for no (no time limit was placed on the response, see Figure 5.2 for trial sequence) - the fixation cross would be shown throughout each phase, including the probe. Participants completed eight blocks of 40 trials, with a practice block of 10 trials that were identical to experimental trials. Participants were given instructions before the practice session; that they must identify their targets in the identification phase, track only their targets in the tracking phase, and that they must maintain representations of their targets if the mask is stationary, or predict trajectories if the mask is a prediction one in order to successfully answer the probe. Participants were told to fixate on the fixation cross throughout the trial, and to perform task demands without making saccades to the objects.

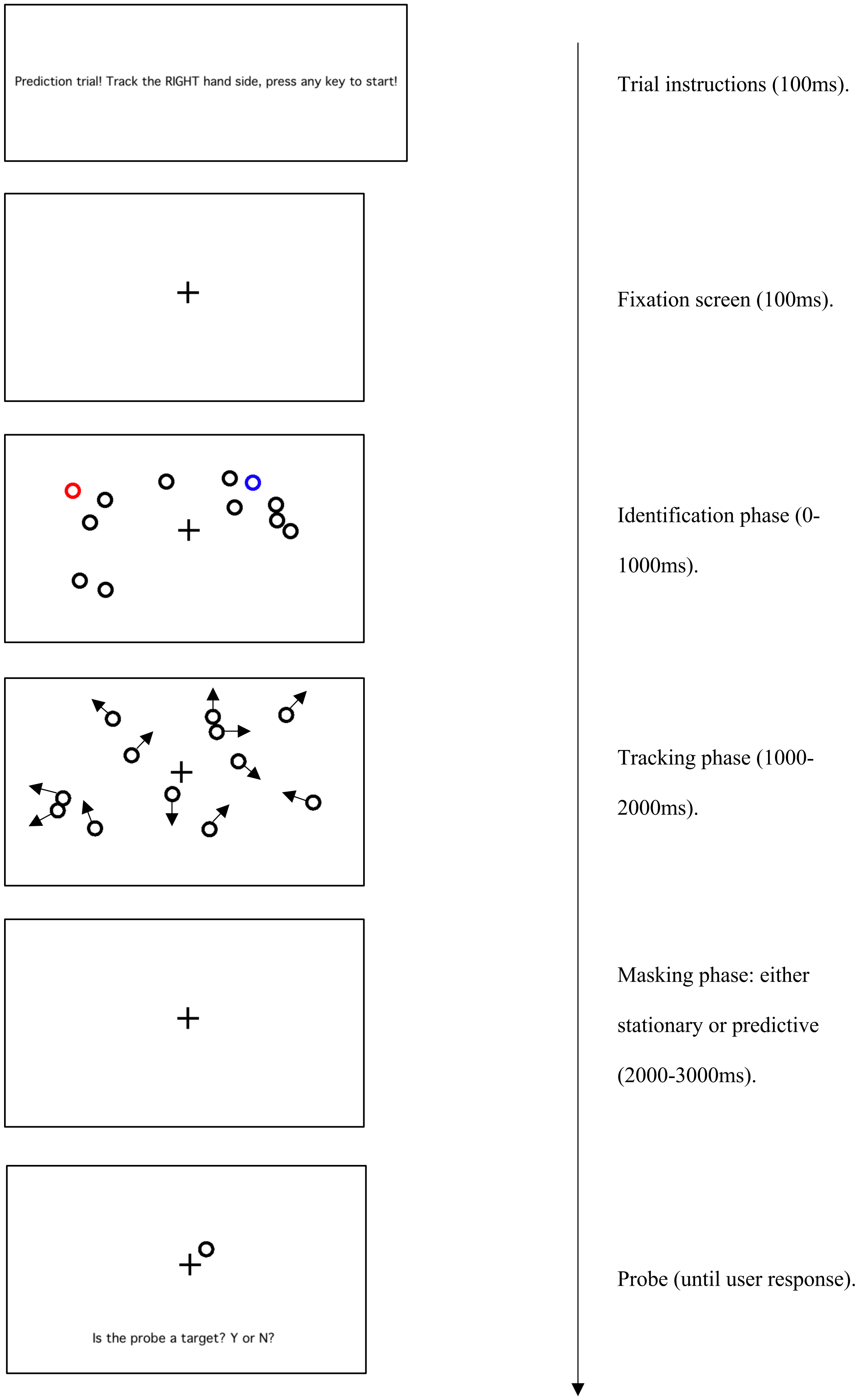


Figure 5.2. Example sequence of a prediction trial with a single target load.

MOT Task - Factors

There were two independent variables in the MOT task; target load, with either one or three targets presented (in each half of the display), and trial nature, with all objects either remaining stationary (stationary mask) or continuing to move (prediction mask). All levels of target load, mask type, and to what side participants were cued to were randomly generated (see Table 5.1 for trial outline). Behavioural accuracy was taken from the probe screen as well as CDA amplitude from each phase; identification, tracking, and masking (see *EEG Recording and Analysis* for more detail).

Table 5.1. Trial outlines for MOT task.

One target		Three targets	
Identification (0-1000ms)	Identification (0-1000ms)	Identification (0-1000ms)	Identification (0-1000ms)
Tracking (1000-2000ms)	Tracking (1000-2000ms)	Tracking (1000-2000ms)	Tracking (1000-2000ms)
Prediction mask (2000-3000ms)	Stationary mask (2000-3000ms)	Prediction mask (2000-3000ms)	Stationary mask (2000-3000ms)

MOT Task - Relevance

The function of this MOT task was to isolate whether individuals with different levels of working memory capacity differ in approach and performance to tracking objects. The addition of the masking phase, compared to the traditional MOT task, will help to facilitate any differences, as all individuals should be able to maintain representations (stationary mask), but additional resources are required to predict trajectories (prediction mask) which all participants may not be able to perform. The measurement of CDA amplitude, as an indicator of the number of items held in visual working memory, will reflect whether individuals are tracking all targets or employing a strategy to track some and not others in order to cope with task demands. The behavioural performance from the MOT task was taken to compare whether differences in approach resulted in differences in performance.

MOT Task - EEG Recording and Analysis

EEG was recorded with silver electrodes mounted on an elastic cap (Easy-Cap) from 26 electrode positions (FP1, FP2, Fz, F3, F4, F7, F8, FCz, FC1, FC2, FC5, FC6, Cz, C3, C4, CP1, CP2, CP5, CP6, Pz, P3, P4, P7, P8, O1, O2), according to the International 10-20 system. Horizontal EOG was recorded bipolarly from the outer canthi of both eyes. Electrical impedances were kept below 5 kΩ, with the impedances of the reference earlobe electrodes as equal as possible. The data was then bandpass filtered at 0.01 – 40 Hz and sampled at 500 Hz using a SynAmps amplifier (NeuroScan), and epoched to 3100ms windows with a baseline of 100ms.

Artefact rejections was completed using ICA, with data being rejected due to linear drift, values that surpassed 75µV, data with improbable distributions (four standard deviations of the datasets mean distribution), high kurtosis, and abnormal spectra. After deletion, a second wave of ICA was run in order to inspect components, here eye-artefacts were deleted on the basis a smooth decrease in the EEG spectrum, a far-frontal projection in the scalp map, and the frequency of eye movements in the component image. Components removed were more likely to be early in the transformation, as eye artefacts tended to be large, and an average of 1.5 components were removed from the dataset per participant, with a maximum of three components removed (for two participants). All analysis was conducted on the corrected data.

In order to compute CDA amplitudes, activity was averaged from the O1, P7, and P3 electrodes (left cluster) and the O2, P4, and P8 electrodes (right cluster). These clusters were then used to compute difference waves by subtracting the response for the ipsilateral hemisphere from the contralateral hemisphere for the respective cued trials. For instance, if the participant was cued to the right, the activity from the right cluster would be subtracted from the left to compute the difference amplitude. These difference waves were then averaged across for trials that were cued to either the right or left. Mean amplitudes were taken for each phase: identification (300-800ms), tracking (1200-1800ms), and masking (2200-2800ms), the slight cropping of the time window was to ensure no confounding carry-over effects from each phase.

AOSPAN Task – Stimuli and Procedure

The AOSPAN was identical to previous versions used in this thesis and has been described in Study 2.2.

AOSPAN Task - Factors and Relevance

The AOSPAN task factors and relevance remained the same as in Study 2.2.

5.1.3 Results

Accuracy

Mean accuracy rates were entered into a mixed effects model, with AOSPAN score, target load, and trial nature as predictor variable, with orthogonal contrast coding used for categorical variables, and in every case the participant was entered into the model as a random effect, bivariate correlations were then run to assess any interactions. A main effect of target load was observed, $F(1,17) = 14.82$, $p < 0.01$, power = 0.09, with higher accuracy rates for one target trials (M = 75.48%, SD = 14.79) than for three target trials (M = 63.39%, SD = 10.81). A main effect of trial nature was also observed, $F(1,17) = 5.19$, $p = 0.03$, power = 0.09, with higher accuracy rates for stationary targets (M = 75.95%, SD = 14.10) than prediction trials (M = 62.93%, SD = 11.17, see Figure 5.3 for main effects).

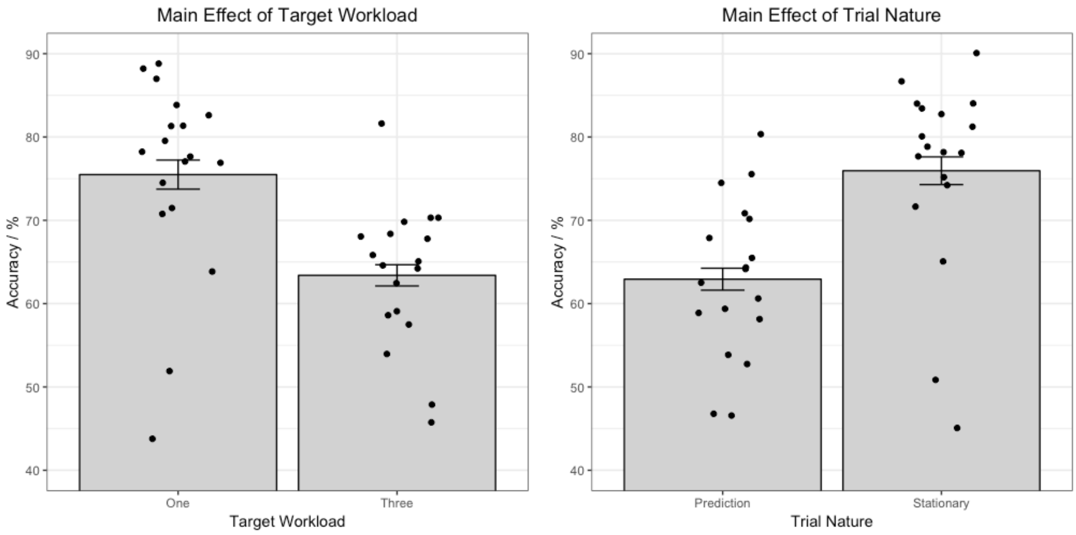


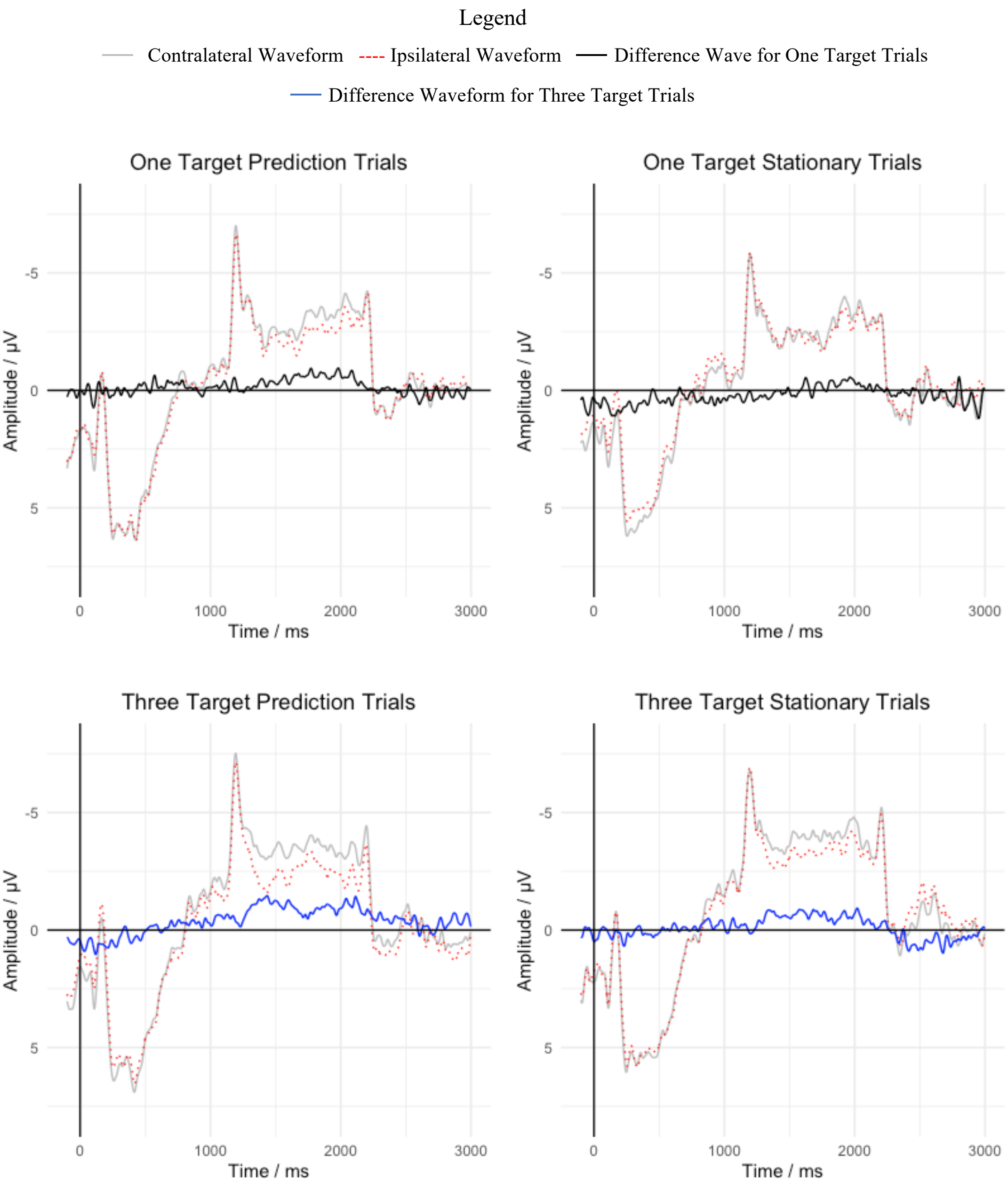
Figure 5.3. Left: Main effect of target load on accuracy. Right: Main effect of trial nature on accuracy, bars denote standard error of the mean, and points denote individual data points for both.

Contralateral Delay Activity

A within subject ANOVA was first conducted to assess contralaterality of the CDA component, this was conducted with trial phase (identify, track, mask), target load (one, three), trial nature (prediction, stationary), and contralaterality (contralateral, ipsilateral) as factors. A main effect of contralaterality was observed, $F(1,18) = 6.60$, $p = 0.02$, $\eta_p^2 = 0.27$, in addition to an interaction between contralaterality and trial phase, $F(2,36) = 4.90$, $p = 0.01$, $\eta_p^2 = 0.21$ (see Table 5.2 Bonferroni corrected comparisons). Mean amplitudes were entered into a mixed effects model, with AOSPAN score, trial phase, target load, and trial nature as the predictor variables, all other parameters remained the same as the analysis for accuracy. An interaction between target load and trial nature was observed as significant, $F(1,17) = 5.34$, $p = 0.02$, power = 0.07. An interaction between AOSPAN score, target load, and trial nature was also observed, $F(1,17) = 6.04$, $p = 0.01$, power = 0.07. Correlations were run across CDA amplitudes and AOSPAN scores in each level separately. An approaching significant relationship was observed between amplitude and AOSPAN score in three target stationary trials, $r = .405$, $p = 0.09$, however, all remaining levels did not reach significance, all $p > 0.13$ (see Figure 5.4 for waveforms and interaction scatterplots).

Table 5.2. Bonferroni corrections for interaction between contralaterality and trial phase.

Trial Phase	*Contralateral / μV*	*Ipsilateral / μV*	*t value*	*p value*
Identify	0.44	0.75	1.54	0.64
Track	-5.67	-4.89	3.81	< 0.01
Mask	-2.45	-2.20	1.21	0.82


Legend
Contralateral Waveform
Ipsilateral Waveform
Difference Wave for One Target Trials
Difference Waveform for Three Target Trials
One Target Prediction Trials
One Target Stationary Trials
Three Target Prediction Trials
Three Target Stationary Trials
Amplitude / µV
-5
0
5
Time / ms
0
1000
2000
3000

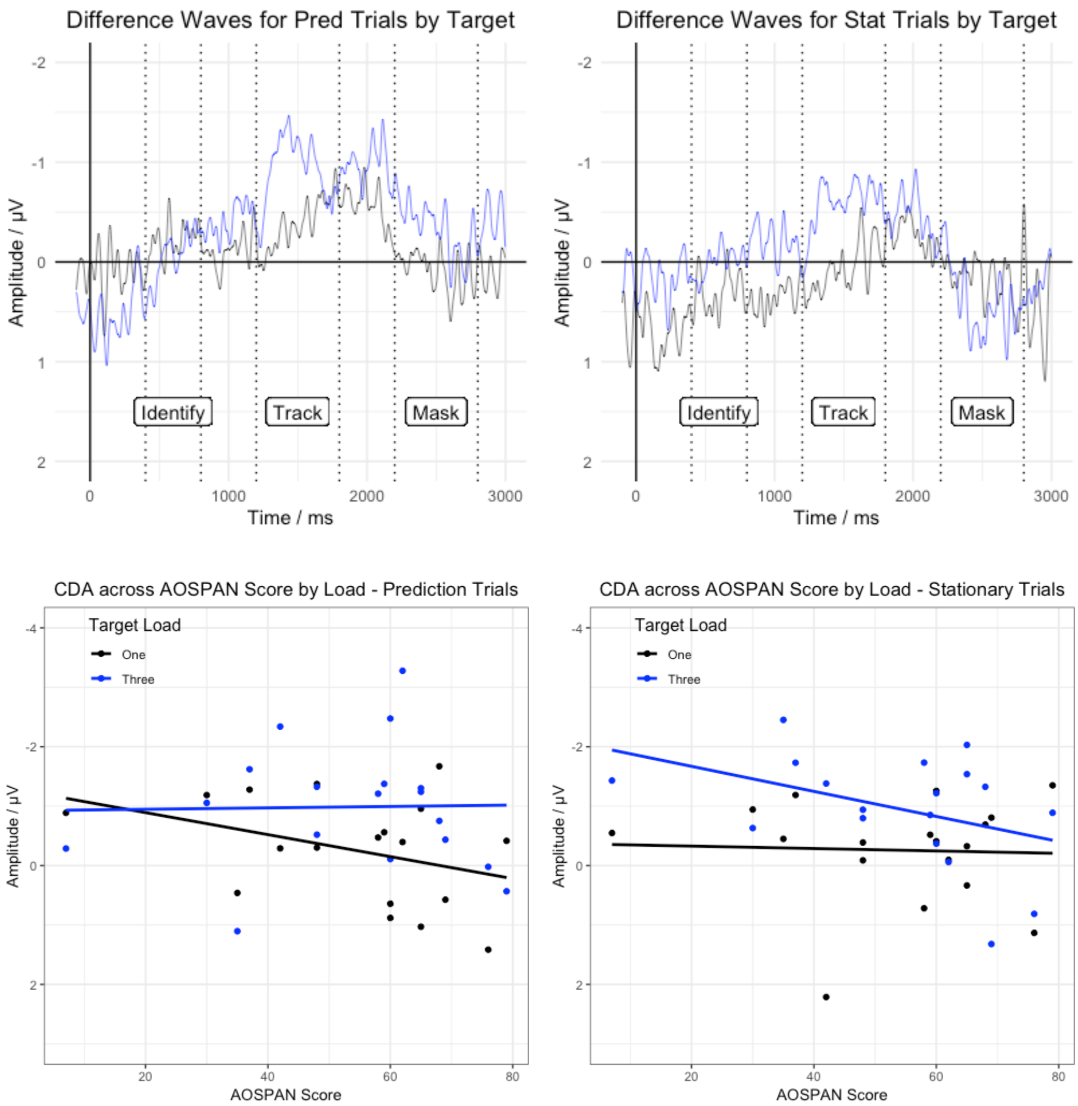


Figure 5.4. First row: Grand averaged waveforms for one target trials for prediction and stationary masks, difference wave is coloured black, negative is plotted up for current and following rows, similarly, waveforms are averaged from the clusters isolated in *MOT Task - EEG Recording and Analysis,* and 0ms represents the onset of the identification phase (see Figure 5.2). Second row: Three target trials for prediction and stationary trials, difference wave is coloured blue. Trial timings and clusters remain the same. Third row: Difference waves plotted for one target (black) and three target (blue) trials, for prediction and stationary masks, dotted lines separate the trial phases: (Identify 400-800ms, Track 1200-1800ms, and Mask (2200-2800ms). Last row: Individual amplitudes averaged over trial phases, plotted against working memory capacity.

5.1.4 Discussion

In summary, results from the behavioural accuracy measures were in line with study hypotheses. Specifically, main effects of target load and trial nature were observed, with greater accuracy observed in stationary compared to prediction trials, and in one target trials compared to three target trials. Furthermore, the working memory capacity of participants had no impact on behavioural accuracy of the task, again, in line with hypotheses. In regard to CDA amplitude, results showed a three-way interaction between working memory capacity, target load, and trial nature. However, after bivariate correlations were run, only an association between working memory capacity and CDA amplitude in three target stationary trials approached significance.

Importantly, a significant effect of contralaterality was only seen in the tracking period of the task. Whilst this represents that participants were eliciting a significant CDA for this period and consequently tracking the movements of targets when asked to, this was not the case during the identification, and more importantly, the masking phase. The lack of a significant CDA during the masking period can be put down to the lack of visible targets, with the general attenuation in signal similar to when participants have been told to pause the tracking of targets in a MOT task (Drew et al., 2011). Results of the contralaterality analysis are therefore suggestive of a post-probe approximation strategy, across all participants, which will be discussed in line with CDA amplitudes in the following section.

The approaching significant correlation between working memory capacity and CDA amplitude in three target stationary trials reflects a relationship where participants with higher capacity scores elicited smaller CDA amplitudes. If thought of independently, the relationship between working memory capacity and CDA amplitude in three target stationary trials suggests that individuals with higher capacity scores in general track fewer items over the course of the trial. This would mean that individuals with fewer resources are essentially inputting more cognitive effort to reach the same behavioural result. Whilst this may be a potential explanation, with lower working memory individuals indeed showing less efficient cognitive strategies (Burra & Kerzel, 2014; Vogel et al., 2005), the isolated nature of the trend means that this is only occurring in trials that do not require prediction but are of a higher target load.

Results from the CDA amplitude analysis therefore do not sit congruently with hypotheses. When the correlation between working memory capacity and CDA amplitude in three target stationary trials is acknowledged alongside both the approaching nature of the significance of this particular correlation, and the lack of correlation across other levels, conclusions can only be drawn in a hesitant fashion. The presence of the increased target load is congruent with divergent neural patterns, with working memory capacity only coming into play when increased cognitive demand is placed on participants. Whereas the lack of difference in prediction trials suggests that the same strategy is being employed across participants, regardless of target load and working memory capacity.

It may therefore be the case that the divergent patterns seen in the current study in higher target load stationary trials are reflective of differences seen in higher demand MOT trials (Drew & Vogel, 2008), with the lack of differences seen in prediction trials reflective of a participant-wide strategy. There are two important notes to take alongside this notion, firstly, the participant-wide strategy in prediction trials may reflect a post-probe approximation (Fenscik et al., 2007). If this is the case, then in the current study targets are not tracked over a trial-gap regardless of target load or resources of the participant. This is supported by the lack of a trial phase interaction, whereby if participants were actively tracking over a trial-gap then an increase from tracking to masking periods would be apparent. It is more strongly supported by the lack of difference across the contralateral and ipsilateral waveforms for the masking period. Secondly, whilst there is an emerging trend in one target prediction trials between working memory capacity and CDA amplitude, the significance was not strong enough to suggest a relationship.

Results from the current study also have implications for surrounding research, the main effect of target load replicates results from previous MOT literature, where an increase in the number of targets reduces the accuracy of responses (Alvarez & Franconeri, 2007; Blumberg et al., 2015; Drew et al., 2011, Drew et al., 2013; Oksama & Hyönä, 2004; Pylyshyn & Storm, 1988), this is also supported by research looking at target load and mixture distribution analysis (Horowitz & Cohen, 2010). Furthermore, the main effect of trial nature replicates findings where accuracy was greater when objects remained stationary in a trial gap as opposed to when participants had to predict trajectories (Keane & Pylyshyn, 2006; Fencsik et al., 2007).

Accuracy did not however depend on working memory capacity, suggesting that although speculative differences were found at the neural level, this did not equate to differences in performance overall. Research that has investigated tracking over a trial gap has not previously used working memory capacity as a predictor for performance (Keane & Pylyshyn, 2006; Fencsik et al., 2007). Furthermore, in more general MOT research, tracking capacity (based on tracking performance scores) was used to predict CDA amplitude (Drew et al., 2011; Drew & Vogel, 2008). However, it is unclear as to why CDA amplitudes did not match tracking demands in the current study, with individual amplitude points consistently keeping below the target demand. Although a reduction in amplitude has been seen when participants have been asked to track beyond limits (Drew & Vogel, 2008), here tracking requirements are within the established threshold of 3-4 items (Alvarez & Cavanagh, 2004; Barton et al., 2005; Cowan, 2000; Luck & Vogel, 1997).

A theoretical account of MOT proposed by Yantis (1992) suggested that higher order representations could play a part in tracking. Individuals may group targets into a visual representation to aid tracking by using summary location statistics to identify targets (Alvarez & Olivia, 2008), where attention is allocated centrally to the formed shape as opposed to the individual objects (Fehd & Seiffert, 2008). Given that the relationship between CDA and complexity of items tracked is still unclear (see Luria et al., 2016), the lack of higher amplitudes may result from individuals grouping targets into a larger representation prior to the trial gap. The tendency to group targets into a higher order visual representation is attenuated under higher target tracking loads (Zelinsky & Neider, 2008), therefore in the following study a supra-capacity display is introduced where participants have to track beyond their capacity. The added target demand would also increase general difficulty, where if the larger set size in the current study does not tax capacity of higher working memory capacity individuals, a target set size of five would do so (Drew & Vogel, 2008).

5.2 Motion Information in MOT across Working Memory Capacity: Beyond Capacities

5.2.1 Introduction

Research Question

The following study builds upon results from Study 5.1 by introducing a 'supra-capacity' display, in order to investigate whether differences in tracking strategy across working memory capacity emerge at loads beyond tracking limits. This supra-capacity display will consist of five targets with five distractors and will aid in investigating whether differences emerge not when task load is within capabilities, but beyond.

Tracking Beyond Limits

The notion of a supra-capacity display in MOT was taken from work by Drew and Vogel (2008), where participants were tasked to track five targets amongst five distractors in a standard MOT paradigm. CDA amplitudes were compared across groups of good and bad trackers, where it was noted that the amplitude of good trackers plateaued at capacity limits (three targets). Whereas participants categorised as bad trackers elicited a regression of CDA amplitude to levels comparable when they were required to track one target. Although the authors do not offer a suggestion to this differing response to the supra-capacity display, they do acknowledge the sensitivity of the CDA to such extreme task demands.

It may however be the case of a compensation between the quality and quantity of tracking in line with limits of individuals. Whereby individuals that have a superior capacity for tracking regress to the limit of three targets, as this is a tracking limit that can be accomplished with a level of accuracy that is enough for task demands. In comparison, those individuals with inferior tracking capabilities regress to one target in a similar vein, where one target is the limit to which tracking can be completed comfortably. This emphasis on higher quality of tracking fewer targets opposed to reduced quality of tracking all required targets may therefore only emerge when the number of targets is beyond the 3-4 established limit.

The flexible resource theory of MOT does provide evidence to support this view, with one target being enough to tax the entirety of tracking resources, if parameters such as speed are kept high enough (Holcombe & Chen, 2012). Therefore, if fewer resources are available to be allocated to a task, then differing measures may be put into place, such as a reactive over a proactive approach, for those that are tasked to track beyond capacity limits. With CDA amplitude reflecting the number of items held in visual working memory, it is clear that when tracking demands exceed capacities, the approach taken to track varies dependent on the individual's tracking capacity.

Although conclusions remain unclear as to why this difference in CDA amplitude emerges, one problem being the inability to differentiate when a target is swapped with a distractor, as both would elicit a CDA amplitude (Drew et al., 2013). The task employed in the current study therefore can provide some clarity to emerging differences in visual tracking by enforcing the prediction requirement in a MOT paradigm. Furthermore, if differences do emerge, results would build upon work illustrating differences based on both tracking capacity groups (Drew & Vogel, 2008) and individual differences (Oksama & Hyönä, 2010) in the MOT. Results would also have implications for Study 5.1, with consequent implications to whether working memory capacity differences can drive variations in approach to tracking in previous paradigms such as the inattentional blindness screening task.

Rationale

The rationale for the current study overlaps greatly with Study 5.1, for both the theoretical implications and the methods used, therefore, this section will focus on the addition of the supra-capacity display. The rationale for the addition of the display was to investigate whether the lack of differences observed in Study 5.1 could be put down to a lack of task demand which in turn did not require active tracking over a trial gap. With the addition of a supra-capacity display observed to trigger divergent neural signatures in the MOT task (Drew & Vogel, 2008), the inclusion of it in the paradigm used in Study 5.1 will isolate whether the prediction of trajectories is a potential strategy for when the number of targets exceed capacity limits. The analysis strategy, specifically the use of linear mixed effects modelling, remained the same.

Hypotheses

The hypotheses will be stated in order that foreshadow the analyses; in regard to accuracy, main effects of accuracy were hypothesised for target load, with greater accuracy for fewer targets. A main effect for trial nature was also hypothesised, with greater accuracy for stationary trials, but with no main effect of working memory capacity or interactions. However, it is hypothesised that working memory capacity will drive differences in CDA amplitude. More specifically, it is hypothesised that individuals with higher working memory capacity will exhibit an increase in CDA amplitude from tracking to masking phases in three and five target prediction trials.

It is consequently also predicted that there will be no change across these phases for one target prediction trials for higher working memory capacity participants, due to a lack of task demand. However, for participants with lower working memory capacity, it is hypothesised that there would be an emphasis on a post-probe approximation strategy, due to a lack of resources to employ tracking over a trial gap. Therefore, such participants will show no change in CDA amplitude across tracking to masking phases in any of the trial conditions (see Figure 5.5 for a graphical representation of the hypotheses).

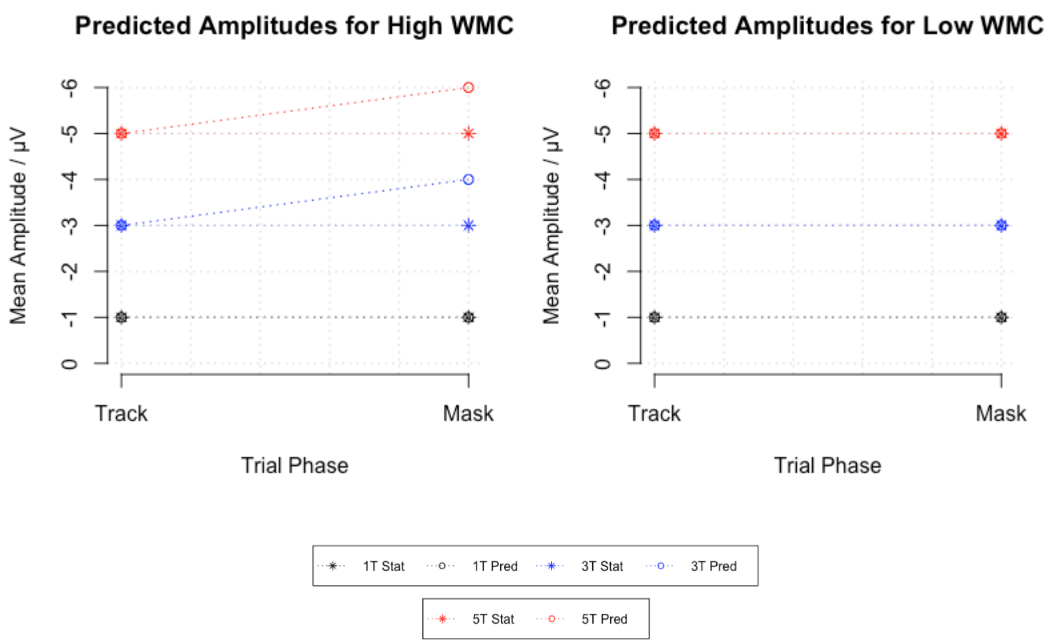


Figure 5.5. Left: Predicted amplitudes for high working memory capacity participants, with an increase in CDA amplitude in prediction trials from tracking to masking periods in three and five targets trials. Right: Predicted amplitudes for low working memory capacity with no change over trial phase for any target load. Bottom: Legend denotes the number of targets and trial nature.

5.2.2 Methods

Participants

A total of 21 participants were recruited using a cloud-based participant management software. All had normal or corrected to normal vision and were naïve to the experimental hypotheses. All experimental procedures were approved by the Birkbeck research ethics committee, and informed consent was taken before testing. Participants were excluded due to noisy EEG data (three participants excluded), and for not reaching the reaction time threshold on the AOSPAN task (two further participants excluded). The remaining 16 participants were aged between 18 - 39 (M = 24.5 years, SD = 4.89; 8 women).

MOT Task - Stimuli and Procedure

Stimuli and procedures remained identical to the MOT task in Study 5.1, with the one exception being the introduction of the five target trials. For these specific trials, the number of distractors were also increased to five (10 objects in total), to maintain balance. Participants completed eight blocks of 40 trials, with a practice block of 10 trials that were identical to experimental trials, including the additional five target trials. Participant instructions remained the same as Study 5.1, with additional information covering the introduction of the five target trials.

MOT Task – Factors

The factors for the MOT task remain identical to Study 5.1, with the addition of a five-target load (see Table 5.3 for updated trial outline). The two independent variables therefore consist of target load (one, three, or five targets), and trial nature (stationary or prediction mask). Measurements of CDA amplitude and behavioural accuracy also remain the same.

Table 5.3 Trial outlines for MOT task with additional target load of five, time windows remain the same.

One target		Three targets		Five Targets	
Identification	Identification	Identification	Identification	Identification	Identification
Tracking	Tracking	Tracking	Tracking	Tracking	Tracking
Prediction mask	Stationary mask	Prediction mask	Stationary mask	Prediction mask	Stationary mask

MOT Task – Relevance

The function of the additional level of five targets is to test whether differences emerge when participants are being asked to track beyond their capacity limits. Although no differences emerge on the basis of working memory capacity in Study 5.1, Drew and Vogel (2008) have documented differences in neural amplitude in good and bad trackers when tracking five targets. Therefore, the five-target load was introduced here, with the existing parameters kept the same.

MOT - EEG Recording and Analysis

All recording and analysis procedures were kept identical to Study 5.1, here the average number of components removed was 1.6, with a maximum of three components removed (for four participants).

AOSPAN Task – Stimuli and Procedure

The AOSPAN was identical to previous versions used in this thesis and has been described in Study 2.2.

AOSPAN Task - Factors and Relevance

The AOSPAN task factors and relevance remained the same as in Study 2.2.

5.2.3 Results

Accuracy

Identical methods were used from Study 5.1, with the inclusion of additional level of target load. A main effect of AOSPAN score was observed, with the correlation showing, r = 0.52, $p = 0.04$, power = 0.09, (Figure 5.6 left). A main effect of target load was also observed, $F(1,15) = 9.05$, $p < 0.01$, power = 0.09, with one target trials (M = 74.6%, SD = 13.03) differing significantly from three (M = 58.8%, SD = 7.75) and five target trials (M = 55.2%, SD = 5.35), $t(15) = 8.35$, $p < 0.01$ and $t(15) = 10.23$, $p < 0.01$ respectively.

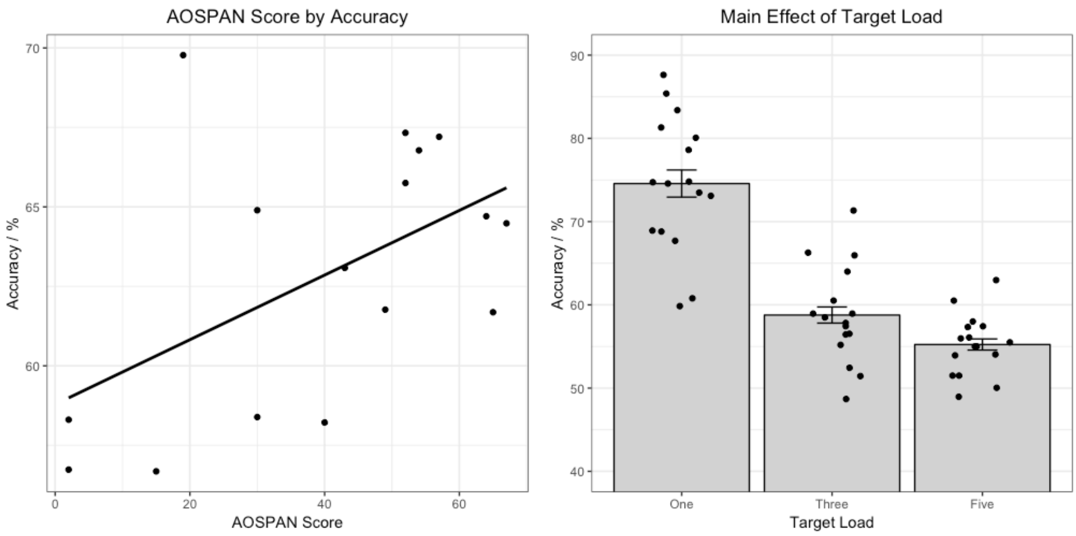


Figure 5.6. Left: Correlation between AOSPAN score and accuracy. Right: Main effect of target load, bars represent standard error of the mean, and dots represent individual datapoints.

Contralateral Delay Activity

Identical methods were used from Study 5.1, with the inclusion of the addition level of target load. This therefore began with a repeated measures ANOVA to test for contralaterality, identical to Study 5.1 but with the additional load. Here a main effect of contralaterality was observed, $F(1,15) = 19.39$, $p < 0.01$, $\eta_p^2 = 0.61$, in addition to the same contralaterality and trial phase interaction, $F(2,30) = 10.16$, $p < 0.01$, $\eta_p^2 = 0.41$ (see Table 5.4 for Bonferroni comparisons). Mean amplitudes were then input into a linear effects model, identical to Study 5.1. A main effect of target load was observed, $F(1,15) = 4.17$, $p = 0.02$, power = 0.08, with an approaching significant difference between three (M = -1.13µV, SD = 1.59) and five target trials (M = -0.73µV SD = 1.37), $t(15) = 2.33$, p = 0.05. A significant difference was also found between one (M = -0.42µV, SD = 1.49) and three target trials, $t(15) = 4.21$, $p < 0.01$.

Table 5.4. Bonferroni corrected comparisons for trial phase by contralaterality interaction.

Trial Phase	*Contralateral / µV*	*Ipsilateral / µV*	*t value*	*p value*
Identify	-3.03	-2.41	2.97	0.10
Track	-6.21	-4.97	5.93	< 0.01
Mask	-2.49	-1.87	2.97	0.10

An interaction was also observed between AOSPAN score, load, and nature, $F(1,15) = 7.81$, $p < 0.01$, power = 0.10. Bivariate correlations for prediction trials did not reveal a significant correlation for any target load in prediction trials, specifically for one target, $r = -0.38$, $p = 0.15$, all others $p > 0.80$. Analysis did reveal a significant correlation between AOSPAN score and CDA amplitude in three target stationary trials, $r = -0.54$, $p = 0.03$, but not for either remaining load, $p > 0.40$ (see Figure 5.7 for waveforms and interaction scatterplots).

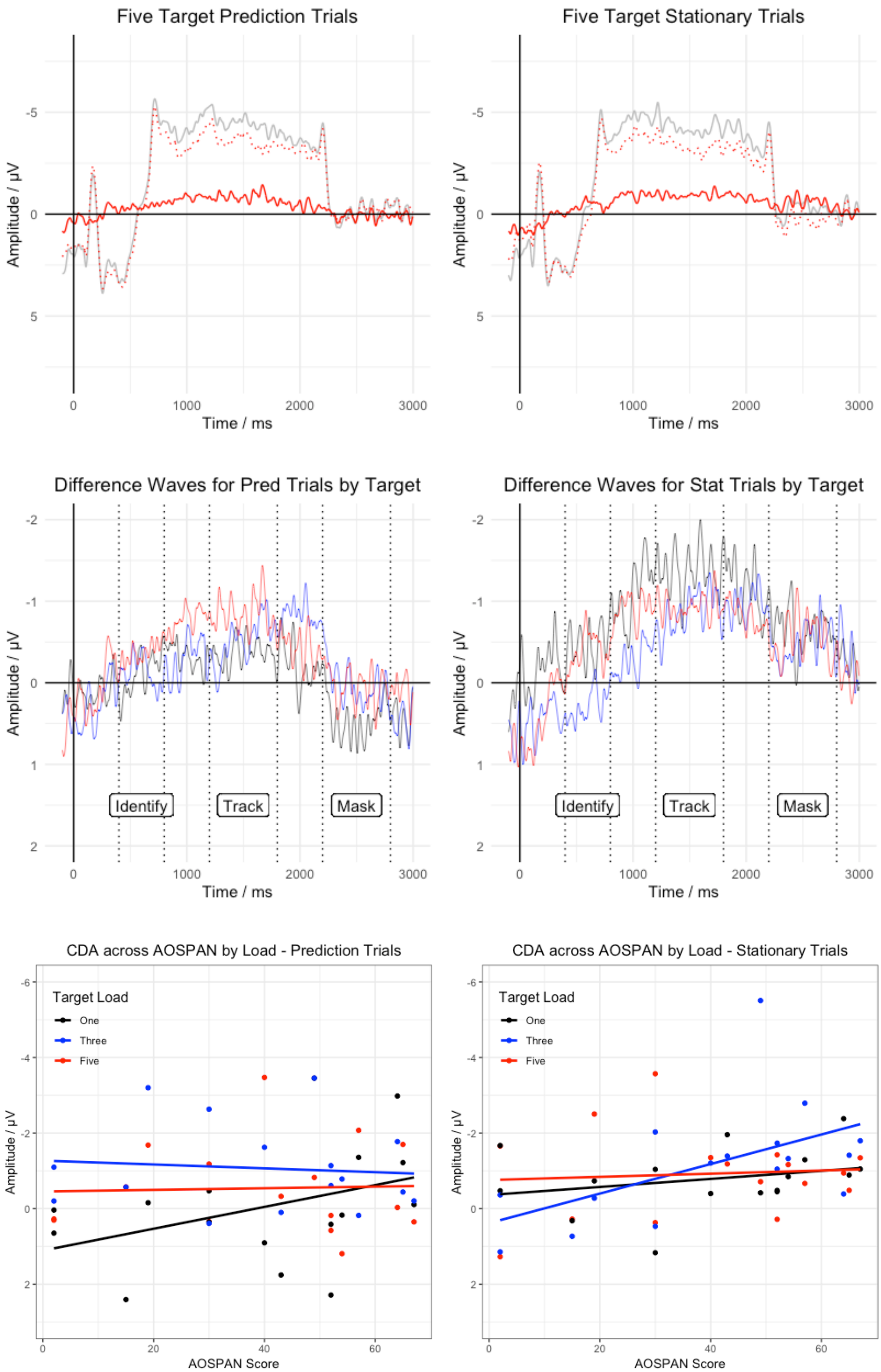

Five Target Prediction Trials
Five Target Stationary Trials
Amplitude / µV
Time / ms
Difference Waves for Pred Trials by Target
Difference Waves for Stat Trials by Target
Identify
Track
Mask
CDA across AOSPAN by Load - Prediction Trials
CDA across AOSPAN by Load - Stationary Trials
Target Load
One
Three
Five
AOSPAN Score

Figure 5.7. First row: Grand averaged waveforms for one target trials for prediction and stationary masks, difference wave is coloured black, negative is plotted up for current and following rows, similarly, waveforms are taken from the clusters identified in *MOT Task - EEG Recording and Analysis,* with 0ms representing the onset of the identification phase. Second row: Three target trials for prediction and stationary trials, difference wave is coloured blue. Third row: Five target trials for prediction and stationary trials, difference wave is coloured red. Fourth row: Difference waves plotted for one target (black), three target (blue) trials, and five target (black) trials, for prediction and stationary masks, dotted lines separate the trial phases: (Identify 400-800ms, Track 1200-1800ms, and Mask 2200-2800ms). Last row: Individual amplitudes averaged over trial phases, plotted against working memory capacity.

5.2.4 Discussion

In summary, results from the behavioural accuracy measures provide some replication from Study 5.1 and justification for the hypotheses. Main effects of target load and trial nature were observed, with greater accuracy observed for one target trials when compared to three and five target trials, in line with study hypotheses and replicating results from Study 5.1. However, interestingly, no main effect of trial nature was observed, and further, a main correlation of working memory capacity with accuracy was observed. Here greater capacity scores were reflective of a greater accuracy overall, but not a trend that interacted with target load or trial nature. Given that this correlation was not present in Study 5.1, and that the only additional level is the five target trials. It can be assumed that this additional level of difficulty triggers an overall performance level that is dependent on the resources of the participant, but not that changes performance on a local scale, for instance, solely within the five-target load.

Although this link has been somewhat shown in the previous application of supra-capacity displays in MOT (Drew & Vogel, 2008), where the differing neural amplitude was observed based on the categorisation of efficient tracking, here the correlation is observed across all target loads. It may therefore be the case that the inclusion of a five-target trial load triggers a knock-on effect for the tracking performance of other target loads. One important note to emphasise is that fact that although in the current study a five-target trial was introduced, the number of trials in the study overall remained the same as Study 5.1. This was maintained in order to keep the level of intensity and interest consistent across the studies, however, does result in lower power per condition. It is possible that interactions with working memory capacity and target load may have appeared if the trial per condition ratio was increased.

In regard to CDA amplitudes, the analysis of contralaterality replicated results from Study 5.1, this is to say that a significant contralateral CDA was observed in only the tracking phase of the trial. This reinforces the view that participants were executing a post-probe approximation strategy in the masking phase of the trial, as no significant difference was observed between contralateral and ipsilateral waves in the masking phase. Results from the linear effects modelling, with CDA amplitudes, also produced the same three-way interaction as seen in Study 5.1 and was somewhat in line with study hypotheses. Interestingly bivariate correlations revealed a sole significant interaction between working memory capacity and CDA amplitudes in three target stationary trials, replicating trends in Study 5.1. However, here the correlation reflected a reverse relationship from what was previously observed, with greater working memory capacity reflective of a greater CDA amplitude. The opposing nature of the results when compared with Study 5.1 does mean that conclusions are difficult to draw.

If taken independently, it would be reflective of a greater allocation of tracking resources (CDA amplitude) in line with the resource capacity of the participant. Whereby, if resources are available, they are allocated to tracking targets in the three target stationary trials. Whilst this does reflect results in the literature, with greater capacity scores reflective of greater allocation of cognitive resources (Drew & Vogel, 2008; Hannon & Richards, 2010; Richards et al., 2010a; Richards et al., 2010b; Papera & Richards, 2017), the correlation within three-target stationary trials does not fit well within the context of the chapter. With the addition of the five-target trial it is unclear as to why the relationship between working memory capacity and CDA amplitude specifically within three-target stationary trials would reverse in the nature shown here. Results must therefore be acknowledged alongside two notions.

The first notion to acknowledge is the same factor that has been mentioned in regard to behavioural results, the reduced ratio of trials to conditions, given the additional five-target load display. This would mean that results in general from the current study lack power when compared to Study 5.1, which may account for the lack of effect for trial nature and smaller distinctions between the target loads in the grand averaged waveforms (Figure 5.7) compared to Study 5.1 (Figure 5.4). The second notion to acknowledge is potential confounding factor of a shift in strategy during the course of the study. Research into the implementation of cognitive control, has isolated a variance in the implementation of strategy by low working memory capacity individuals (Weimers & Redick, 2018). This consequently has implications for the current chapter, in the sense that although varying neural signatures may give rise to equal performance across working memory capacity, the varying neural signatures may in turn vary across the study for low working memory capacity participants.

Analysis into CDA amplitude also observed a main effect of target load with greater CDA amplitude seen in three target trials compared to both one and five target trials. This general trend reflects the CDA amplitude seen in the 'bad' tracking group in the Drew and Vogel (2008) study, however, given the additional requirement for participants to actively track targets over a trial-gap, general amplitudes here may be relatively more comparable to the inefficient tracking group. This is to say that at five target trials, tracking amplitudes resemble amplitudes at one target trials due to a compensation in the quality and quantity in tracking, where it is more attainable to track fewer targets well, than more targets at a reduced efficiency. Furthermore, analysis into CDA amplitudes also observed interactions between trial phase and target load, and target load and trial nature. However, as these interactions were not hypothesised a priori, and do not include the working memory capacity measure they are not discussed further.

Results in the current study build upon results in Study 5.1 and retain implications for surrounding literature. While lower behavioural accuracy has also been observed when five target trials have been included in tracking tasks (Fencsik et al., 2007), novel results from the current study suggest that the working memory capacity of individuals is predictive of the accuracy obtained when five-target trials are included in task demands. The main effect of target load on CDA amplitude also carries a similar trend to research investigating supra-capacity tracking (Drew & Vogel, 2008), where here a general attenuation of CDA amplitude was observed, not one dependent on ability to track. Interestingly, whilst mean amplitude in the Drew and Vogel (2008) paper shows a smaller discrepancy compared to actual targets presented, the mean amplitudes in the current study are similar to amplitudes observed in Study 5.1, with an amplitude of just over -1µV for three target trials. Therefore, whilst a similar trend is present, the amplitude of the trend remains far smaller.

The explanation for this trend offered in the previous study was that three targets may not necessarily demand the maximum level of effort in tracking, especially for participants with a higher working memory capacity. However, if that were the case, the main effect of load here would reflect a linear trend, where five target trials should elicit a CDA amplitude greater than three target trials. Although some research has suggested at the influence of activity silent representations in working memory (Trübutschek et al., 2017; Stokes, 2015; Watanabe & Funahashi, 2014), more recent research has shown that activity silent representations reflect only short-term storage, and that manipulation of this information elicited persistent neuronal activity (Trübutschek, Marti, Ueberschär, & Dehaene, 2019). The speed at which objects moved matched work on CDA and MOT (Doran & Hoffman, 2011; Drew et al., 2013; Drew et al., 2012; Drew & Vogel, 2008) and was below the limit established for each set size (Alvarez & Franconeri, 2007), although quicker trajectories have been used for free viewing, behavioural MOT tasks (Fencsik et al., 2007). Therefore, the lack of higher amplitudes for each target load cannot be put down to a discrepancy in speed. Instead, five targets may not be a target set size large enough to restrict a perceptual grouping strategy.

The final study in the current chapter will attempt to isolate whether differences emerge over the course of a study, that ultimately may affect the end averaged result. Given the research that illustrates individuals with low working memory capacity exhibit a shift towards proactive cognitive control over the course of a task (Weimers & Redick, 2018), and that expectancy-based strategies in a Stroop paradigm were dependent on the availability of working memory resources (Ortells et al., 2017; Ortells et al., 2018). The next study will assess if there are any changes over the course of the task, this will be facilitated through assigning target load in a block fashion, allowing for a comparison of early task and late task performance.

5.3 Motion Information in MOT across Working Memory Capacity: Flexibility in Resource Allocation

5.3.1 Introduction

Research Question

The following study aims to investigate whether change in strategy to tracking targets in a MOT is dependent on working memory capacity. Specifically, whether individuals with lower working memory capacity change in tracking strategy over the course of a study, which may be apparent through changes in CDA amplitude but not behavioural accuracy of trials. The study will replicate the paradigm from Study 5.1 but will include a comparison of CDA amplitude from each half of testing to investigate if the approach to tracking varies. Datasets from Studies 5.1 and 5.2 will also be combined with the dataset in the current study to increase power.

Proactive and Reactive Control

Goal maintenance can be argued to be imperative for the selection of conflicting responses under cognitive load, for instance, maintaining the identity of targets amidst distractors when tracking trajectories and bounces in an inattentional blindness screening task. Successful preparatory activity of this sort has been categorised as proactive control (Braver, Burgess & Gray, 2007), this involves anticipatory and sustained maintenance of goal representations. This is contrary to a more 'wait and see' approach termed as reactive control, where goal representations are reactivated by stimuli acting as triggers. With working memory capacity involving processes such as temporary storage, active manipulation, and the retrieval of information to serve the purpose of a goal, it is logical to see a positive correlation between capacity and attentional control (Engle & Kane, 2004). An example of a theory that attempts to explain the temporal dynamics of how approaches differ is the dual mechanism of cognitive control (Braver et al., 2012).

The implementation of proactive control has been found to be influenced by a number of internal factors such as practice (Paxton et al., 2006), incentives (Braver, Paxton, Locke, & Barch, 2009), and most importantly, working memory capacity (Redick, 2014). The translation of differing cognitive approach into action has been demonstrated in a number of studies and real-world examples. These range from the utilisation of cues by high working memory capacity participants in a reaction time task (AX continuous performance test, Redick, 2014, see also Ball, 2015; Redick & Engle, 2011; Richmond, Redick, & Braver, 2015, Weimers & Redick, 2018), where low working memory capacity participants instead rely on overall response frequencies for instance. This reaction time task allowed responses to be prepared (proactive control) to a probe based on information from a prior cue, this approach would then result in high performance on certain trials that were aided by this association, but lower performance on trials that include an interference with the target response. A pattern exhibited by high working memory capacity participants.

Alternatively, participants with low working memory capacity exhibited a reactive strategy where responses were prepared when the probe was presented and information from the cue was reactivated. This resulted in greater performance in the interference trials, compared to proactive participants, but generally slower performance on trials that require an association to cue. What is of more relevance to the work in this study is how cognitive control strategies translate to action in more real-world settings. For instance, when driving at a busy junction a proactive approach would entail the flagging of possible vehicles that carry a potential risk that would have to be averted through stopping or steering. This would therefore entail identifying such targets and predicting trajectories to assess whether they carry a risk. The alternative, reactive strategy would therefore be to rely on quick behavioural responses (such as swerving) only when threats emerge, carrying a higher chance of accidents.

The proactive approach in the real-world example therefore involves the use of trajectory predictions in order to keep up with the demands of the situation. Given the link to proactive control and high working memory capacity (Richmond et al., 2015; Redick & Engle, 2011; Redick 2014; Weimers & Redick, 2018), it was the aim of both Study 5.1 and 5.2 to isolate the propensity to predict trajectories of targets when a surplus of working memory resources was available. Whilst results have not been conclusive across Studies 5.1 and 5.2, one key area to assess that carries implications for the results of both studies is the continuous implementation of a specific strategy. Specifically, research has demonstrated that individuals with lower working memory capacity shift in implementation from reactive control to proactive control over the course of an experiment (Weimers & Redick, 2018).

This intra-individual variability however is exhibited both ways, with high working memory capacity individuals eliciting a more efficient switch to reactive control when required (Redick, 2014; Richmond et al., 2015). Given that proactive control has been suggested to be more cognitive demanding (Braver, 2012), this switch can be made more easily by high-capacity individuals that do not ordinarily struggle with cognitive tasks such as goal maintenance and response conflict. However, the point remains that low-capacity individuals have been shown to elicit a switch to proactive control when given time on the task. This therefore has implications as to whether differences across working memory capacity did emerge but were masked by not comparing strategy use by differing capacity participants across the study.

Rationale

The rationale for the current study is to therefore assess whether participants, specifically low working memory capacity participants, shift in tracking approach within a MOT task. Results will then feed into the wider question of whether differences emerge neurally that equate to the same behavioural result. Whilst research has been conducted in the shift in cognitive control across level of working memory capacity, and also in the implementation of the prediction of target trajectories when tracking, research has yet to identify whether such prediction can be used as a proactive approach by high working memory capacity individuals.

Furthermore, research has yet to identify whether a shift in strategy for low working memory capacity individuals, from reactive to proactive, can include an intensive approach such trajectory prediction – which can be considered more cognitive demanding than using prior cue information to aid response conflict. Lastly, an additional analysis was conducted in the current study to address the lack of power in Studies 5.1 and 5.2. Given the emerging yet contrasting correlations found in both studies, especially within three-target stationary trials, there is a clear rationale for combining datasets across the chapter in order to assess whether any robust effects are observed. The approach of linear mixed effects modelling remained the same.

Hypotheses

The hypotheses will be stated in order that foreshadow the analysis, in regard to accuracy it is expected that trends follow from Study 5.1, with main effects hypothesised for both target load and trial nature. It is hypothesised that greater accuracy will be seen for one target trials compared to three target trials, and that greater accuracy will be seen for stationary trials compared to prediction trials. However, as per previous studies in this chapter, it is hypothesised that accuracy will not vary dependent on working memory capacity, or that working memory will interact with either target load or trial nature for accuracy rates.

In regard to the CDA amplitude, for prediction trials, it is hypothesised that low working memory capacity participants will exhibit an increase in change of CDA amplitude from tracking to masking periods in the second half of the study compared to the first half. This would reflect a shift in strategy as more CDA activity would reflect an engagement in the prediction of target trajectories in the masking period, compared to a reduced CDA amplitude, which would reflect a post-probe approximation strategy. However, for high working memory capacity individuals it is hypothesised that no change will be observed, as a proactive strategy would be implemented throughout the study, therefore for prediction trials, the same level of CDA amplitude is hypothesised throughout.

For stationary trials, it is hypothesised that both high and low working memory capacity individuals will exhibit no change over the course of the study, as the cognitive demands of maintaining representations should be met by all participants. The datasets from Studies 5.1 and 5.2 will be also be combined with the dataset in the current study to generate more power in order to assess the relationship between CDA amplitude, working memory capacity, and tracking in the MOT. Data from Study 5.2 will only include amplitude data from trials that had one or three targets, as no other study contained five target trials.

5.3.2 Methods

Participants

A total of 18 participants were recruited using a cloud-based participant management software. All had normal or corrected to normal vision and were naïve to the experimental hypotheses. All experimental procedures were approved by the Birkbeck research ethics committee, and informed consent was taken before testing. Participants were excluded due to noisy EEG data (no participants excluded), and for not reaching the reaction time threshold on the AOSPAN task (three participants excluded). The remaining 15 participants were aged between 23 - 40 (M = 29.5 years, SD = 9; 8 women).

MOT Task - Stimuli and Procedure

Stimuli and procedures were kept identical to Study 5.1, with two exceptions; firstly, the target load was kept consistent within blocks, secondly, as the task was split into two halves, each half contained four blocks (two blocks of one target trials and two blocks of three target trials). This was programmed into the study to make sure comparison of performance over the course of the task was viable, however, the order of blocks within each half was randomised. Participant instructions remained the same as Study 5.1, with additional information that target load would be kept consistent within a block, but not that performance would be compared across the two halves of the task.

MOT Task – Factors

The factors for the MOT task remain identical to Study 5.1 (see Table 5.5 for updated trial outline). The two independent variables therefore consist of target load (one or three targets), and trial nature (stationary or prediction mask). Measurements of behavioural accuracy to the probe and CDA amplitude also remain the same, with the inclusion of a difference CDA amplitude in order to assess how strategy changes over the task. Here neural activity from the second half of the study was subtracted from the first half, therefore, negative amplitudes reflected fewer items tracked (more positive CDA) across the two halves of the task, and positive amplitudes reflected more items tracked (more negative CDA).

Table 5.5. Trial outlines for MOT task with target loads and comparison of two halves of the study, time windows remain the same.

First half				Second half			
One target		Three targets		One target		Three targets	
Identify	Identify	Identify	Identify	Identify	Identify	Identify	Identify
Track	Track	Track	Track	Track	Track	Track	Track
Pred M	Stat M	Pred M	Stat M	Pred M	Stat M	Pred M	Stat M

MOT Task – Relevance

Whilst differences do emerge in relation to working memory capacity in Study 5.2, the five target load trials are excluded here in order to maintain the same level of trials per condition as Study 5.1 – an issue that might have contributed to a weaker signal in Study 5.2. Furthermore, an additional function of Study 5.3 is to isolate whether differences emerge over the course of the task, therefore the trial structure was set out so that a comparison could be made from the second half to the first half.

If CDA amplitude becomes more negative over the course of the study it would reflect participants tracking more objects, where a more positive amplitude would reflect fewer objects being tracked. This measure will assess whether working memory capacity dictates how consistent participants are with the approach in tracking, given that low working memory capacity individuals show a tendency to shift in approach when given time on the task (Weimers & Redick, 2018).

MOT Task - EEG Recording and Analysis

All recording and analysis procedures were kept identical to Study 5.1, with the one additional level of analysis being the comparison of CDA amplitudes over the course of the task. Here the same procedure was followed as the standard analysis for mean CDA amplitudes but separated by either the first or second half of the task, with the subtraction of amplitudes then producing the final measurement. The average number of components removed from the ICA was two, with a maximum of three components removed (for three participants).

AOSPAN Task – Stimuli and Procedure

The AOSPAN was identical to previous versions used in this thesis and has been described in Study 2.2.

AOSPAN Task - Factors and Relevance

The AOSPAN task factors and relevance remained the same as in Study 2.2.

5.3.3 Results

Accuracy

Identical methods were used from Study 5.1, here a main effect of load was observed, $F(1,14) = 20.33$, $p < 0.01$, power = 0.08, with higher accuracy for one target trials (M = 77.52%, SD = 12.02) than for three target trials (M = 62.92%, SD = 8.79). A main effect of trial nature was also observed, $F(1,14) = 4.82$, $p = 0.03$, power = 0.08 (see Figure 5.8 for both main effects), with higher accuracy seen for stationary trials (M = 76.24%, SD = 12.46) compared to prediction trials (M = 64.21%, SD = 10.10).

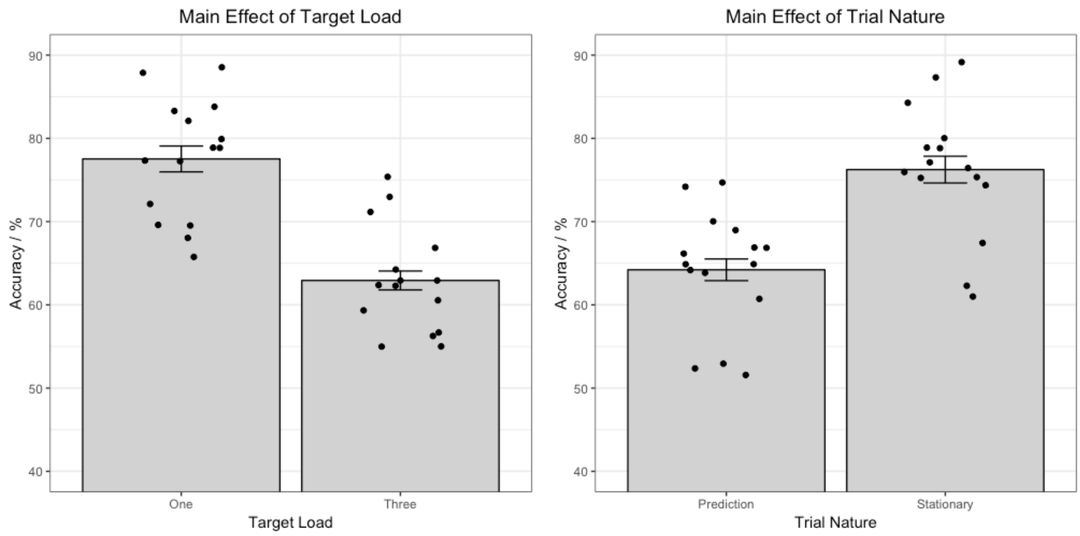
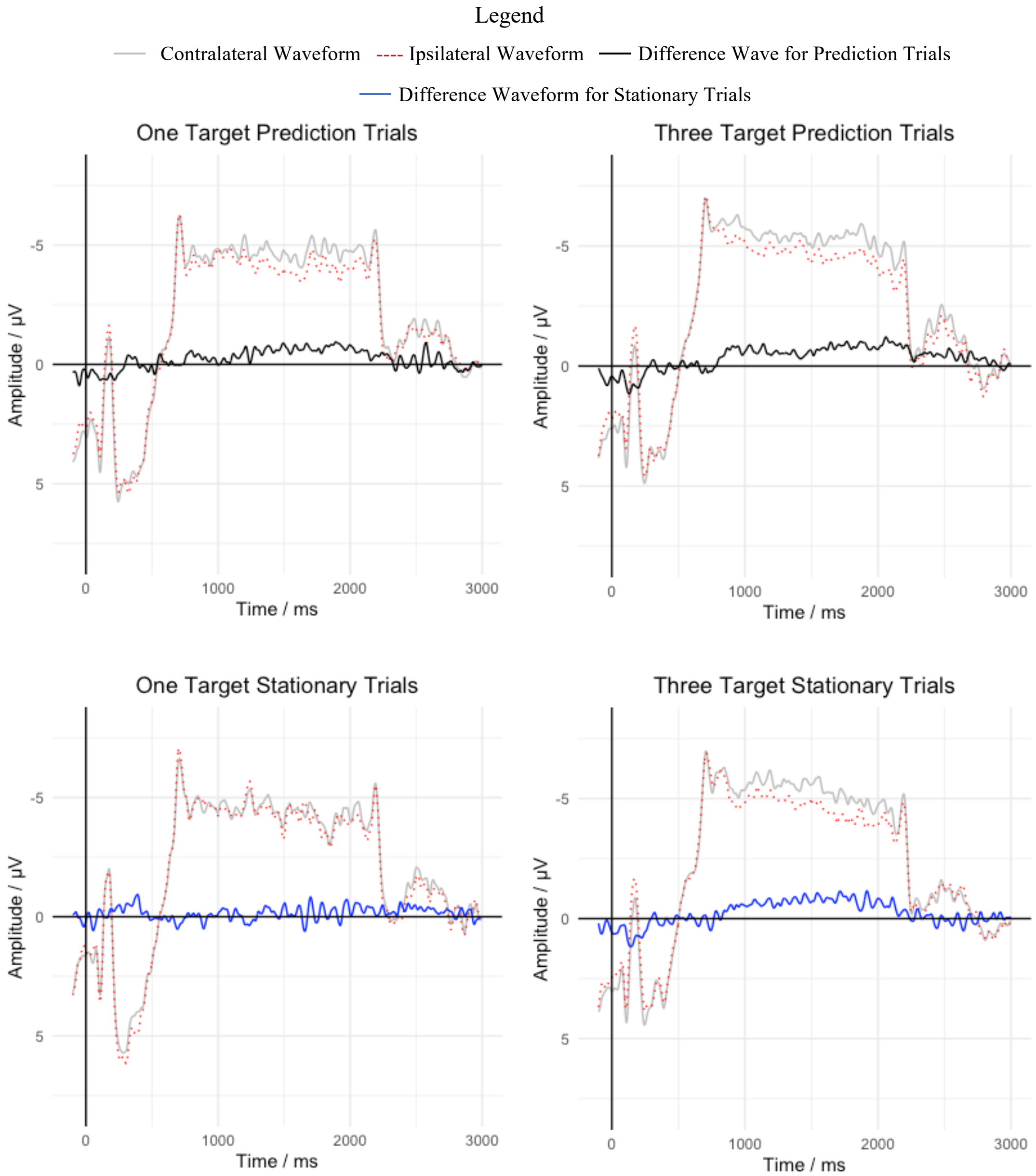


Figure 5.8. Left: Main effect of target load on accuracy. Right: Main effect of trial nature on accuracy, bars represent standard error of the mean, points denote data points.

Contralateral Delay Activity

To begin with, amplitudes were submitted to a within subject ANOVA to test for contralaterality in an identical method to Study 5.1. Whilst no main effect of contralaterality was observed $F(1,14) = 0.39$, $p = 0.54$, $\eta_p^2 = 0.02$, an interaction between contralaterality, trial phase, and trial nature was significant, $F(2,28) = 4.17$, $p = 0.02$, $\eta_p^2 = 0.23$, although no Bonferroni corrected comparisons were observed as significant. Analysis on CDA amplitudes were carried out across the MOT task, identical to Study 5.1, with a linear mixed effects model. Here a main effect of target load was observed, $F(1,14) = 12.43$, $p < 0.01$, power = 0.19, with higher CDA amplitudes observed for three target trials (M = -0.91μV, SD = 1.04) than for one target trials (M = -0.56μV, SD = 0.83). An interaction between AOSPAN score and load was also observed, $F(1,14) = 5.50$, $p = 0.02$, however, correlations observed no significant correlations for either load, one, $r = -0.24$, $p = 0.39$, three, $r = 0.26$, $p = 0.35$.

Secondly, CDA amplitudes were compared across the two halves of the MOT task, this was done by taking CDA amplitude from the second half of the task and subtracting from the first half. Each half contained an iteration of trial conditions (see Table 5.3); therefore, negative numbers denoted a reduction in change (more positive CDA amplitude) which denoted an individual tracking fewer items over the course of the task. Positive numbers then denoted an increase in change (more negative CDA amplitude) which in turn reflected an increase in the number of targets tracked over the course of the task. A main effect of trial nature was observed, $F(1,14) = 15.76$, $p < 0.01$, power = 0.08, with a reduction in CDA amplitude for prediction trials (M = -0.42μV, SD = 1.71) and an increase in CDA amplitude for stationary trials (M = 0.11μV, SD = 2.08). An interaction between AOSPAN score and trial nature was also observed, $F(1,14) = 10.34$, $p = < 0.01$, power = 0.09, (Figure 5.9), but whilst contrasting trends were present, neither achieved significance: prediction, $r = 0.23$, $p = 0.42$, stationary, $r = -0.32$, $p = 0.25$.


Legend
Contralateral Waveform
Ipsilateral Waveform
Difference Wave for Prediction Trials
Difference Waveform for Stationary Trials
One Target Prediction Trials
Three Target Prediction Trials
One Target Stationary Trials
Three Target Stationary Trials
Amplitude / µV
-5
0
5
Time / ms
0
1000
2000
3000

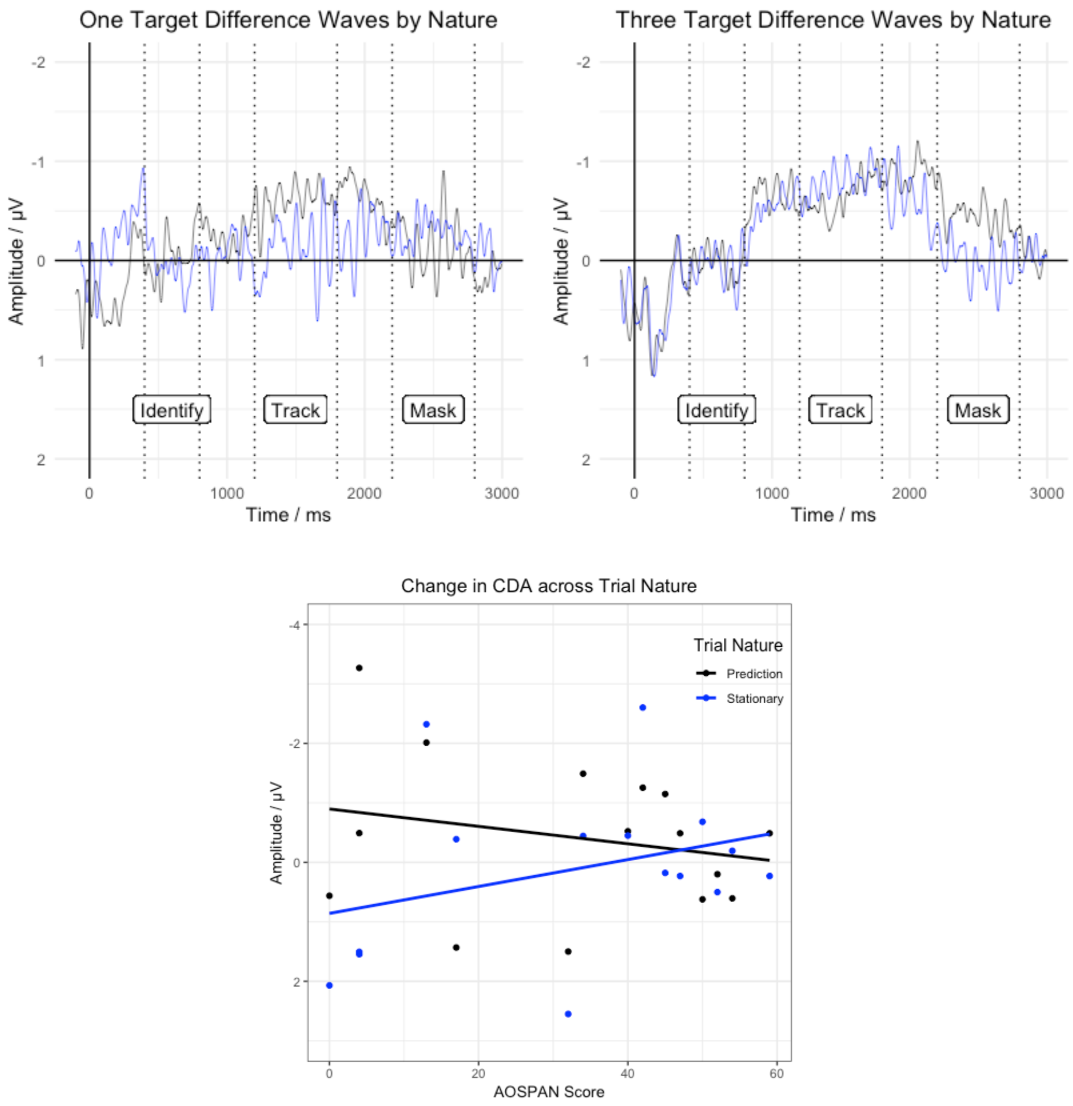


Figure 5.9. First row: Grand averaged waveforms for one target (left) and three targets (right) prediction trials, negative is plotted upwards for all graphs in the figure, similarly, waveforms are taken from the clusters identified in *MOT Task - EEG Recording and Analysis,* with 0ms representing the onset of the identification phase. Second row: Grand averaged waveforms for one target (left) and three target (right) stationary trials. Third Row: Difference waveforms separated by trial nature for one target trials (left) and three target trials (right), the vertical dotted lines and markers denote the stage of the trial (Identify 400-800ms, Track 1200-1800ms, and Mask (2200-2800ms). Fourth row: Amplitude change from the first half to second half of the experiment for each participant, separated by trial nature only. Positive numbers denote an increase in CDA (from -1 to -3, tracking more), whereas negative numbers denote a reduction in CDA (-3 to -1, tracking fewer).

Combined Datasets

Participants from studies 5.1, 5.2, and 5.3 were combined in order to assess the relationship between CDA amplitude and working memory capacity, this was taken from target loads one and three from all studies (N = 49), thus, excluding the supra-capacity display in Study 5.2. A significant main effect of load was observed, $F(1,48) = 12.07$, $p < 0.01$, power = 0.22, with mean amplitudes higher in three target trials (M = -1.00μV, SD = 1.16) compared to one target trials (M = -0.40μV, SD = 1.13). Furthermore, an approaching significant effect was observed for AOSPAN scores, target load, and trial nature, $F(1,48) = 3.12$, $p = 0.08$, here bivariate correlations revealed no significant correlations for prediction or stationary trials, all *p*s > .38 (see Figure 5.10).

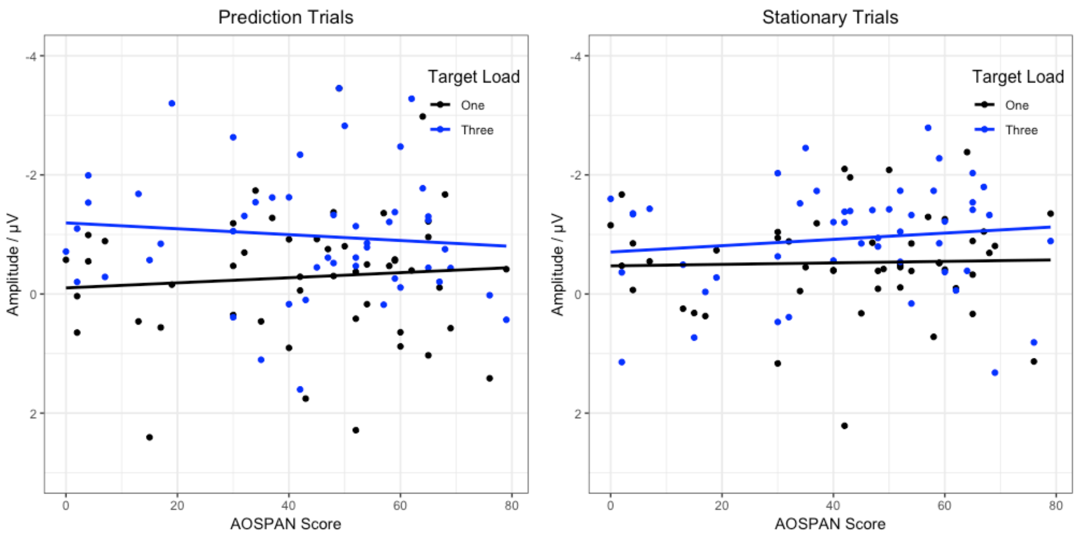


Figure 5.10. Left: CDA amplitude across AOSPAN score by target load for prediction trials. Right: The same but for stationary trials.

5.3.4 Discussion

In summary, results from the behavioural accuracy measures were in line with study hypotheses and replicated results from Study 5.1. Main effects of both target load and trial nature were observed, with greater accuracy for one target trials compared to three target trials, and for stationary trials compared to prediction trials, as seen in Study 5.1. The overall correlation between accuracy and working memory capacity observed in Study 5.2 was not observed here; and given the factor of five-target trials being the main difference in Study 5.2 compared to others in the chapter, it does suggest that the inclusion of the supra-capacity display may trigger a general performance pattern that is dependent on capacity resources. This could manifest itself through the implementation of a strategy, which is dictated by working memory capacity, specifically for five-target trials, but due to the random trial order, is then applied to all target loads. If it was the case that working memory capacity only influenced accuracy in five-target trials, then the correlation would only be observed for that target load and independently.

Results from the contralaterality analysis in the current study did not replicate results from previous studies in this chapter. Whilst an interaction was found between trial phase, trial nature, and contralaterality, no comparisons were found to be significant after corrections. This may in part be due to high number of conditions in this interaction coupled with the lower number of participants. Furthermore, it may be reflective of the overall difficulty of the paradigm, whilst change detection tasks elicit stationary targets bilaterally, here a MOT task was shown in both the left and right side of the display. This was done in order to make sure differences across contralateral and ipsilateral waves were not just due to sensory activity, for instance, observing a significant difference because no stimuli were present on the opposing side. Given that a moving stimulus is more attention grabbing than one that is stationary, for instance in the change detection task, the difference amplitudes in the current study may have been facilitated better with a unilateral display.

Conclusions must therefore be made with caution, as it is not explicit that participants elicited a robust CDA to the cued side of the MOT task. Analysis into the CDA amplitudes were first conducted across the entirety of the study, identical to Study 5.1. Here a main effect of load was replicated from Study 5.2, with a greater CDA amplitude observed for three-target trials compared to one-target trials. The lack of consistency, specifically in Study 5.1 for the effect of target load on CDA amplitudes can be put down to the varying sample sizes obtained across the studies. The second component of CDA amplitude analysis was to compared amplitude change from each half of the task, and whether the degree of change was dependent on working memory capacity. Hypotheses regarding change in CDA amplitude predicted that participants with low working memory capacity would shift in strategy for tracking. This would be observable by an increase in CDA amplitude from tracking to masking periods for prediction trials, as this would reflect a more proactive strategy of tracking across the trial-gap instead of a post-probe approximation.

Results from the change in CDA amplitude analysis somewhat support a priori hypotheses. Firstly, a main effect of trial nature was observed, whereby an increase in CDA amplitude was observed for stationary trials and a decrease in prediction trials. This is to say that all participants elicited a greater CDA amplitude in the second half of the study in comparison to the first half for stationary trials, suggestive of a performance where more targets were tracked. However, although an increase in CDA amplitude was observed in stationary trials, the magnitude of the difference was small (0.11µV), it is therefore difficult to isolate whether this difference can be linked to an increase in the actual number of targets tracked. This is less applicable to prediction trials, where a reduction in CDA amplitude was observed over the course of the task. Participants, in general, elicited an attenuated CDA amplitude in the second half compared to the first half, this reduction in amplitude is reflective a decrease in the number of items tracked, and is more robust given the magnitude of the reduction (-0.42μV).

In context however, the greater difference observed in prediction trials may reflect the tendency for all participants to shift to a post-probe approximation strategy, as this would elicit a smaller CDA amplitude than active tracking. The CDA analysis also observed an interaction between working memory capacity and trial nature, and whilst trends were apparent, no significant bivariate correlations were observed. The contrasting trends however do still provide insight into the change in CDA amplitude over the course of the task, by observing individual datapoints in Figure 5.9 it is apparent that lower working memory capacity participants carry a greater propensity for change. Greater differences in change for both stationary and prediction trials are apparent at this lower end of the working memory capacity spectrum, and in both conditions, attenuate as working memory capacity increases. Whilst correlations were not observed to be significant in this interaction, the contrasting trends do suggest that differences may be present, and in line with literature showing a shift in strategy for lower working memory participants when given time on task (Weimers & Redick, 2018).

The final part of the CDA analysis was to combine datasets from both studies 5.1 and 5.2 with the current dataset to increase power. With the increased sample size, a main effect of target load was observed, with an increased CDA amplitude for three-target trials compared to one-target trials. Whilst a main effect of target load was observed in Study 5.2, it was absent in Study 5.1, however given the replication of the effect in the current study and the presence in the combined dataset, it can be concluded that the CDA amplitude is reflective of the target load in MOT. The combined dataset also produced an interaction between working memory capacity, target load, and trial nature – an interaction that was present in both Study 5.1 and Study 5.2. Although individual bivariate correlations did not produce any significant relationships, contrasting trends were present in the scatterplot (Figure 5.10). These contrasting trends do somewhat replicate the results observed in Study 5.2, where an increase in CDA amplitude for higher working memory capacity participants was observed for three-target stationary trials. Similarly, a decrease in CDA amplitude was observed for higher working memory capacity participants in three-target prediction trials, a trend not observed previously. However, given the correlations did not approach significance the contrasting trends are not robust enough to be discussed with implications. It may however be the case that performance over the course of the task is a confounding factor for Studies 5.1 and 5.2, and that CDA amplitudes for low working memory capacity participants are averaged to a smaller results due time on the task.

Results from the current study carry a number of implications for surrounding research. In accordance with the theory of dual mechanisms of control (Braver, 2012; Braver et al., 2007), individuals with higher working memory capacity engage proactive control more frequently. Whilst practice can facilitate the use of proactive control in older adults (Braver et al., 2009; Paxton et al., 2006), the reduction in CDA amplitude in prediction trials by lower working memory capacity participants suggests that practice is not the determining factor. The results here tentatively suggest that a change in strategy can occur in absence of explicit instructions (Gonthier et al., 2016, Edwards et al., 2010). If it is the case that proactive and reactive strategy use is a determining factor in tracking visual items, then the role of working memory capacity in inattentional blindness may in turn revolve whether individuals with lower working memory are failing to implement proactive control when tracking.

Research has linked a failure to use proactive control to lapses in attention (McVay & Kane, 2009; Unsworth & McMillan, 2014), where it is not that case that low working memory capacity individuals do not implement proactive control as efficiently but are simply less likely to do so. This may manifest itself where a lapse in attention may interfere with representations in working memory, for instance in a cue probe period, and consequently the participant has to rely on reactive measures instead of being able to allocate resources in a preparatory manner (Weimers & Redick, 2018). Papera and Richards (2016) proposed a similar notion from a neural perspective for explaining inattentional blindness, where low oscillatory power (Dehaene & Changeux, 2011; Jensen et al., 2012) may play a part in preventing stimuli from accessing conscious awareness. Dehaene and Changeux (2011; 2005) explained that a strong temporary increase in synchronised firing of neurons can cause a coherent state of activity, which competes with rather than facilitates the processing of sensory stimuli. This coherent state of activity, coined 'ignition', is a product of bottom-up propagation and top-down amplification, with high spontaneous activity facilitating the detection of weak stimuli, but very high spontaneous activity triggering a blocking effect.

Papera and Richards (2016) observed that individuals that carry this propensity to miss visual items show a poor amplification of early targets. This consequently means that early activity fails to reach the threshold to achieve a synchronous spread of activation to brain areas that would reflect conscious maintenance (Dehaene & Changeux, 2011). Theta band power has also been linked to the deployment of resources (Papera & Richards, 2016), the level of cognitive effort required to store items (Zakrzewsha & Brzezicka, 2014), and the speed of the oscillatory activity linked to individual capacity (Wolinski, Cooper, Sauseng, & Romei, 2018). The implementation of cognitive control strategy therefore carries link to visual tracking in two manners: firstly, in the more traditional sense an inefficient deployment of resources in a preparatory fashion is linked to lower working memory capacity. Secondly however, a reactive strategy may also be employed because individuals with lower working memory are more prone to attentional slips, for instance through the neural theory for inattentional blindness (Papera & Richards, 2016, see also Dehaene & Changeux, 2011).

To summarise, results from Study 5.3 provide some novel insights into the relationship between working memory capacity and changes in visual tracking across a MOT task. Although results are tentative due to lack of significance across hemispheres, I do believe that there is a precedent for investigating the change in approach that is elicited asymmetrically across the working memory capacity spectrum when tracking visual targets. This is emphasised by the greater propensity for change in CDA amplitude by lower working memory capacity participants compared to those at higher capacity. In the next section, results from all three studies in the current chapter will be summarised, discussed, and critiqued.

5.4 General Discussion

The current chapter consists of three studies that attempted to investigate the relationship between working memory capacity and visual tracking approaches in MOT. The premise behind the methods used was to investigate whether participants tracked targets over a trial-gap or instead relied on a post-probe approximation measure, and whether this potential differing strategy was dependent on working memory resources. Therefore, a trial-gap (coined masking period in the current chapter) was introduced to the traditional MOT paradigm. Study 5.1 attempted to investigate whether lower working memory capacity participants implemented this post-probe approximation when explicitly being asked to track across the trial-gap. It was hypothesised that behavioural accuracy would not differ dependent on working memory capacity. However, CDA amplitude, an index of the number of items tracked in visual working memory, would be higher in the masking period for higher working memory capacity participants as it would reflect active tracking over the trial gap.

Results from Study 5.1 did not support initial hypotheses, where the only change in CDA amplitude that was dependent on working memory capacity occurred in three-target stationary trials. Study 5.2 introduced the hypothesis that Study 5.1 may not have carried enough cognitive demand in order for working memory capacity to dictate tracking strategies and given that a supra-capacity display had been shown to trigger divergent CDA amplitudes in previous literature (Drew & Vogel, 2008), it was introduced to Study 5.2. Results from Study 5.2 however also proved inconclusive. Whilst novel insights were gained over the two studies it was proposed that a confounding factor for the previous two studies could be the varying implementation of cognitive control strategies over the course of the task.

Study 5.3 then attempted to investigate whether lower working memory capacity participants vary in their approach to tracking when given time on task. This was proposed to have manifested from a reactive, post-probe approximation of the target, to a more proactive, active tracking across the trial-gap approach. Results did suggest that lower working memory capacity showed a higher propensity for change in CDA amplitude compared to those with a higher capacity, with behavioural accuracy not dependent on working memory capacity scores. The results do begin to suggest the impact of working memory capacity on visual tracking, with implication for not only tasks such as the MOT, but also paradigms that contain a visual tracking component, such as the inattentional blindness task. The results specifically implicate the role of numerous routes, based on capacity scores and applied cognitive control strategies, that ultimately result in comparable behavioural results.

However, two important aspects that reduce the conclusiveness of results from the current chapter are the contralaterality analysis and, linked, the lack of replication of results. Results from the studies in this chapter still carry implications for general cognitive tracking mechanisms as one of the key areas of investigation was whether the working memory capacity of individuals was a predictor of performance across either the projection of trajectories or maintenance of representations when tracking. Given that trial phase was not a significant predictor in any of the studies presented, and that a robust CDA was not elicited in the masking phases, it is strongly suggestive that participants did not differ in approach when asked to predict trajectories or not, regardless of experimental parameters or working memory capacity. Research has suggested that over a trial-gap, participants use a spatial pre- and post-gap estimation (Fencsik et al., 2007; Keane & Pylyshyn, 2006), and even during smaller occlusions, where smaller errors were found when trajectories were erroneously closer to pre-gap locations (Fraconeri et al., 2012), which seems to have been implemented by all participants in the three studies presented here.

Work in the chapter also attempted to increase power by amalgamating the samples from each study and then implementing the same analysis on CDA amplitudes. A robust main effect of target load was observed, with a greater CDA component for three target trials compared to one target trials, congruent with work that the paradigm was based upon. Furthermore, the interaction between working memory capacity, target load, and trial nature was also observed again, however, with no significant correlations or clear trends in the data. Although speculations were made regarding the differences in CDA data for the three-way interaction, I believe the most consequential finding of the chapter is suggestion of differing trends of change across the MOT task (Study 5.3), as the finding therefore has implication for previous work investigating differences in low working memory capacity.

Therefore, the robust effect of target load on CDA amplitude across the amalgamated dataset is an important finding, as previous work has implicated the effect of target load in a traditional MOT task, not one with an integrated trial-gap, like in the current chapter. However, the trend that suggests the higher variance in CDA amplitude in low working memory capacity individuals across the duration of the MOT task has both implications for work done averaging results from such a cohort and provides an avenue for further research. Results from Studies 5.1 and 5.2 both averaged over the duration of the MOT task, and the process of doing so, in conjunction with results from Study 5.3 may provide some explanation to the contrasting trends shown in three-target stationary trials. Given the fewer trials available for each condition in Study 5.2, there may have been less of an opportunity for change (as there is less time on task for each condition, resulting in less familiarity), resulting in a smaller CDA amplitude on average for low working memory capacity participants.

This notion, of undetected change during the task influencing averaged results, therefore has implications for theories of MOT and working memory in general. The correlation between working memory capacity and behavioural accuracy in Study 5.2 does fit well with research suggesting the role of working memory and attention is not as necessary under lighter cognitive loads compared to more intense ones (Lavie, 2005; Lavie, Hirst, de Fockert, & Viding, 2004; Doran & Hoffman, 2010). It may suggest that whilst at lower loads, diverging strategies can be implemented by different levels of working memory capacity to achieve comparable performance, at higher levels, demands can only be met through an increased capacity of resources. Furthermore, the change in amplitude across Study 5.3 is suggestive of that whilst a fixed limit does exist on the number of targets that can be efficiently tracked per participant (Oksama & Hyönä, 2004), there is flexibility beneath that to allocate resources varyingly.

The trend of varying CDA amplitude in Study 5.3 also therefore sits well with Zhang and Luck's (2008) juice-box analogy to representations in visual working memory. Here 'juice-boxes' represent the slots available in visual working memory, and whilst the number of slots remain discrete, the 'juice' which then represents the resources that are available to allocate, can be done so in a flexible manner. Work in the current chapter therefore extends findings of flexible resource allocation to representations in visual working memory to the tracking of multiple objects, with emphasis on a trial-gap. Where previous research has investigated trial-gaps in MOT using behavioural measures (Horowitz et al., 2006; Iordanescu et al., 2009; Keane & Pylyshyn, 2006), and target tracking without a trial gap through the CDA (Drew et al., 2011; Drew et al., 2012), work in the current chapter has shown that an amalgamation of methods (trial gap with CDA recording) can help to shed light on varying neural patterns that may act as compensatory mechanisms for performance.

Lastly, work in the current chapter has also shown evidence for differing cognitive control strategies in MOT. Results from 5.3 reflect previous research that has shown a difference in approach to a cognitive task, dependent of working memory capacity (Weimers & Redick, 2018). Whilst it is also true that the allocation of resources may not always follow experimental cues: errors in visual cueing tasks have been shown to decrease monotopically with increasing priority (Yoo, Klyszejko, Curtis & Ma, 2018), with the strategy implemented not reflecting one of proportional probability (Emrich et al., 2017). Instead, relative to experimental probe probabilities, resources were under-allocated to high-priority targets, and over-allocated to low-priority targets, a strategy congruent with minimizing expected loss as this would lower the probability of large errors for low-priority targets, whilst not jeopardising high priority cues to a large extent (Yoo et al., 2018). Such research, combined with the results from Study 5.3, does make the case for a stronger, further investigation into whether cognitive control strategies can be used to understand differences in neural amplitudes within a MOT task. Which in turn has implications for the tracking of targets both specifically in the inattentional blindness task, but also more generally, in real world situations.

Limitations of the Contralateral Delay Activity Component

Whilst the previous section has advocated for the role of the CDA in both works completed in this chapter, and for future avenues of research, recent research has identified controversy as to what the amplitude reflects. Therefore, briefly here such research will be summarised. There is a varying degree of evidence to support the link between the CDA and the level of complexity of items maintained in visual working memory. Firstly, there is a general agreement that working memory capacity is a mental resource pool with a limit, whether arguments are made supporting a fixed upper limit model (Miller, 1956; Luck & Vogel, 1997; Pashler, 1988; Cowan, 2001) or one where resolution is compensated for quantity (Bays, 2018). A consequence of this restraint is the interplay between resources and the simplification of the items held, there is evidence for the argument that CDA amplitude does not represent an index for complexity, with amplitudes not changing when polygon stimuli were halved in order to reduce complexity (Balaban & Luria, 2015), or colour resolution (Ye et al., 2014), but with the broad overview that the amplitude reflects the number of items maintained in working memory.

In contrast to this position, is the attentional activation hypothesis, which proposes that CDA amplitude represents the current focus of attention (Berggren & Eimer, 2016). It is suggested that previous studies of CDA encourage attention and the encoding of the cued stimuli to occur simultaneously, and that the amplitude of CDA in change detection and MOT tasks reflect not the maintenance of objects, but a representation of focal attention to new targets. (Drew et al., 2011). Research has also suggested that items that are stored in working memory are not always analogous in their activation levels (Lewis-Peacock, Drysdale, Oberauer, & Postle, 2012), this is also evident through the notion of activity silent representations (Rose et al., 2016). This would be redolent that the CDA, as a neural indicator of activity in working memory storage, may not be all encompassing.

However, counter evidence to the attentional activation account suggests that mechanisms that underlie evidence for the CDA representing the current focus in spatial attention can also be explained through participants retrieving representations from a passive memory state (Feldmann-Wüstefeld, Vogel, & Awh, 2018). This was postulated in opposition to the attentional activation account through the notion of a de-prioritisation of encoded episodes, through LTM or activity silent representations, with retrieval completed when required (Feldmann-Wüstefeld et al., 2018). Despite the evidence against, it can be effectively stated that the CDA serves as an index for the number of items held in working memory capacity, particularly for this thesis, as the MOT has shown to isolate the CDA in previous, similar tasks. Although, conclusions have to be taken in line with the lack of replication of CDA trends across the three MOT tasks, and the lack of contralaterality in Study 5.3.

Conclusion

In conclusion, this chapter has emphasised the importance of measures of working memory resources in the performance of tracking visual objects. Whilst a direct influence may only present itself under loads that push individuals past tracking limits, work has suggested at an indirect influence. Individuals with lower working memory capacity may diverge in their strategy over time in order to compensate for a lower pool of resources. Whilst only speculative, results here carry implications for research using working memory capacity in order to predict behavioural outcomes such as inattentional blindness or sensitivity to violations in realistic visual displays.

Chapter 6. Discussion

6.1 Overview of Chapter

The aim of this chapter is to provide a summary of the results from the thesis and consequent implications for current and future research. The chapter itself will be separated into the following sections: first, a summary of findings will be presented from each chapter, with an emphasis on important themes of findings from the thesis. To follow, the implications of these findings will be discussed for current theories. After which the limitations of the studies presented in this thesis will be evaluated, with directions for future research proposed. The chapter will conclude with some final remarks.

6.2 Summary of Results

The first experimental chapter of the thesis investigated whether differences in sensitivity to images that carry violations differ as a function of inattentional blindness categorisation. Study 2.1 observed no differences across inattentional blindness rates for accuracy or reaction times when categorising images as real or artificial, neither did inattentional blindness groups differ in working memory capacity. Main effects observed an emerging speed and accuracy trade-off, as reaction times were quicker for violated images, but accuracy was greater for natural images. Study 2.2 again showed no differences across levels of inattentional blindness for either sensitivity to violations in image textures, or in regard to capacity limits. Results did however show a main effect in the N2pc latency, suggesting participant-wide differences in sensitivity to violations. Specifically, regardless of inattentional blindness categorisation an increased amplitude (more positive) was observed for high violated images compared to natural images.

Study 3.1 attempted to build upon exploratory work completed in the previous chapter, to investigate whether autoregressive patches could be used to fill gaps in real world image textures in order to isolate attentional processes across working memory capacity groups. However, no significant effects were found, and whilst a number of potential confounding factors around the design were considered, the method of introducing patches through autoregressive filling was concluded to not be as effective as image quilting. The first two experimental chapters of this thesis sought to lay the groundwork to investigate the differences in attentional processing across inattentional blindness and working memory capacity in real world images. However, thereafter the thesis moved to investigate whether working memory capacity was also influenced strategies in tracking, which would in turn influence inattentional blindness categorisation.

Study 4.1 investigated whether differences in working memory capacity group predict differences in tracking strategy in a novel object tracking task. The study aimed to assess whether the use of motion information was predicted by capacity limits. However, only a main effect of trial phase was found, where all participants lost more distance on the target square when it deviated unexpectedly, suggesting a participant-wide reliance on motion information when tracking a single target. Study 4.2 attempted to address a number of limitations of the previous study by introducing a new dependent variable and encouraging eye fixations. Through measuring the time participants spent outside of the target pathway threshold, main effects of distractor load and trial nature were observed. Furthermore, participants with greater working memory capacity exhibited greater POT (they spent more time outside the tracking threshold) in both stationary trials, and when no distractors were present, with no other associations with working memory capacity observed in related levels.

The last experiment chapter transitioned to a more established paradigm, the MOT task, due to the ability to correlate neural amplitudes to tracking performance and potential strategies. A trial gap was introduced in order to assess if working memory capacity dictated whether prediction of target trajectories using motion information was used. Whilst a main effect of target load was observed, only an approaching correlation between working memory capacity and CDA amplitude in three target stationary trials suggested that participants with greater capacity tracked fewer items in this particular manipulation. However, no effects on accuracy were observed across working memory capacity level, suggesting that whilst the number of items tracked may differ across working memory capacity the ability to perform accurately was not dependent on neural differences.

Study 5.2 introduced a supra-capacity display involving five targets, to increase tracking demands on participants. A correlation was observed between accuracy rates and working memory capacity, which was hypothesised due to low working memory capacity participants not being able to meet task demands. Whilst the same three-way interaction was observed, between working memory capacity, target load, and trial nature, a negative correlation was observed in three target stationary trials. Here participants with greater capacity measures elicited a greater CDA amplitude throughout the trial, however, no difference in amplitude was observed across trial phases, suggesting that all participants still exhibited a pre- and post-trial gap estimation. It was acknowledged that a lower trial per condition factor may have contributed to the inconsistency of effects across studies 5.1 and 5.2.

Another confounding factor that was hypothesised to contribute to inconsistent results across Chapter 5 was that of shifting strategies in the MOT task. Study 5.3 attempted to address whether a shift in strategy was present in lower working memory capacities. With the exclusion of five target trials, main effects of target load and trial nature on accuracy rates were observed. However, more importantly, suggestions of a change in tracking strategy were observed over the course of the study by lower working memory capacity participants. Greater differences in change of CDA amplitude over the study were apparent in both stationary and prediction trials for lower capacity participants, which attenuated as working memory capacity increased. Furthermore, whilst individual bivariate correlations were not significant, the trends present were in line with research that supported the rationale and hypothesis of the study (Weimers & Redick, 2018). Results were offered in this study alongside the hesitancy of a lack of significant difference across hemispheres for the bilateral MOT display.

Study 5.3 also combined datasets across all three studies, excluding the five target trials in Study 5.2, in order to increase power. A main effect of load was observed within CDA amplitude, concurrent with results in Study 5.2 and 5.3. Furthermore, an interaction between target load, trial nature, and working memory capacity was again observed. However, individual bivariate correlations revealed no significant relationships, although given the suggestive trends of change in CDA amplitude for lower capacity participants (Study 5.3), change in strategy may be an unaccounted confounding factor in the combined dataset. One important theme to take from the studies in Chapter 5 is that there was no change in CDA amplitude from tracking to masking phase. The prediction that a change would occur was argued to represent an 'attentional high-beam' effect, where participants were actively tracking a target through an occlusion. However, a lack of change suggested that a post-trial gap estimation was taking place, where all participants estimate the identity of the probe based on where targets were last seen, based on location information and not motion information.

Results in this thesis can be broadly categorising into two themes: differences in sensitivity to semanticity in distractor images and divergent strategies in object tracking. On the back of research conducted in this thesis, I would argue that the main finding for each is that firstly, differences in early sensitivity to violations in image textures do exist in the N2pc range. Secondly, the use of motion information is not dependent on working memory capacity in a MOT task, but that strategy in lower capacity participants may change over the course of the study. Both the main themes and the smaller findings from the thesis therefore have a number of implications for surrounding literature, in addition to wider relevance, which will be discussed in the next section.

6.3 Implications for Current Research

Working Memory Capacity and Inattentional Blindness

Whilst the primary aim of Chapter 2 was to investigate differences in sensitivity to violations in image textures across inattentional blindness, both Study 2.1 and 2.2 attempted to replicate research supporting the resource-based hypothesis of inattentional blindness. However, no significant differences across inattentional blindness groups were found using either a visual spatial test (CBTT) or a more central executive test (AOSPAN). Findings from the thesis therefore fail to provide support for a difference in working memory capacity across inattentional blindness

(Hannon & Richards, 2010; Papera & Richards, 2017; Richards et al., 2010; Richards et al., 2012; Richards et al., 2014; Seegmiller et al., 2011), and suggest that inattentional blindness is, if at all, only tentatively associated with working memory capacity (see Beanland & Chan, 2016).

Additional factors in the literature, such as the dual-route model, whereby individuals with higher working memory capacity inhibit the unexpected change due to the task-irrelevance, were controlled for by using a screening task that introduced a change in target stimuli. This is opposed to a new stimulus that does not fit into any stimulus category, such as a red cross. Therefore, the impact of the dual-route model would have been small on capacity difference tests completed in Chapter 2. Furthermore, work suggesting that participants that do not observe the change on the full-attention trial also elicit a form of inattentional blindness (White et al., 2018) does not have a great impact on work conducted in this thesis. Only a single participant was excluded due to inattention on the full attentional trial, therefore, the theory put forward by White and colleagues is more relevant for the consistency of research conducted in inattentional blindness, and not for this entire thesis.

Work in this thesis transitioned from investigating differences across inattentional blindness to differences across the working memory capacity spectrum. One reason for this was to maintain links to inattentional blindness research and the resource-based hypothesis while investigating potential mediating factors, however, these remain tentative. This was due to the lack of differences in capacity scores in Chapter 2, but also the limitations of a one trial screening paradigm. Work conducted in this thesis therefore adds to the view that inattentional blindness should be discussed as a propensity as opposed to a capacity-based trait. An interesting trend that did emerge across the latter half of this thesis, however, is that approach to tracking can diverge as a function of working memory capacity. Given that the inattentional blindness screening paradigm is one that employs tracking processes, in conjunction with inhibitory processes, results from this thesis have also put forward strong rationales to examine how such strategies influence rates on inattention.

Whilst inattentional blindness may carry an unreliable link to working memory capacity, it may be the strategy of tracking targets, which from work in this thesis has shown can be influenced by capacity limits, that results in more resources being free to notice an unexpected change. This is a novel finding, and whilst the emphasis within this thesis turned to capacity limits and trajectory predictions, I do believe it is a finding which warrants further investigation into the phenomenon of inattentional blindness and its manifestations in real-world contexts.

Application of Image Manipulation Methods

I will firstly discuss implications of image manipulation methods in inattentional blindness, then progress onto discussing the novel methods used here for wider research purposes. Regardless of the implications of an existing or non-existing relationship between inattentional blindness and working memory capacity, work in this thesis has demonstrated that methods that involve the manipulation of real-world textures can be applied to investigate the manifestation of inattentional blindness. Research in the area has investigated the incidence of inattentional blindness in settings that carry much more external validity, such as counting basketball passes with an unexpected stimulus appearance (Simon & Chabris, 1999), or the reporting of a staged fight when completing a primary observation task (Chabris et al., 2011). However, the majority of inattentional blindness research has been firstly classified on the basis of a tracking track (see Most et al., 2001 for original), and secondly associated with performance on low-level visual search tasks (Papera et al., 2014; Papera & Richards, 2016).

The latter work allows for an estimation of saliency through bottom up featural aspects such as luminance and orientation (Papera et al., 2014), but the lack of semantic information in such displays means that findings may not directly extrapolate to instance of inattentional blindness in real life (Lehr & Attersley, 2009). This is pertinent given that the speed of object categorisation has shown to be influenced by simultaneous, unexpected objects that remain undetected (Schnuerch, Kreitz, Gibbons, & Memmert, 2016). It suggests that the mental representations of objects missing during inattentional blindness are processed to a semantic level. Chapter 2 therefore provides a foundation for transitioning inattentional blindness research from artificial visual arrays to natural arrays that still carry the capacity for systematic manipulation. In doing so, proposals such as investigating the level of saliency difference required for inattentionally blind and non-inattentionally blind to achieve comparable performance can be carried out with visual displays that carry semantic information.

Work in this thesis also has implications for more wider literature in semantic processing. Results in Study 2.2 are the first to my knowledge to demonstrate differences in the N2pc latency in response to violations in real-world image textures. Results build upon work by Balas and Conlin (2015), showing a N1 sensitivity to image created through the Portilla-Simoncell approach (2000). While an increased N1 amplitude was observed for real textures, work in this thesis extends findings to suggest that this sensitivity difference can then be subject to inhibition or enhancement, in the N2 latency, due to the presence of violations. Furthermore, whilst differences in the N1 latency were observed in Study 2.2, individual comparisons did not reach significance. This lack of difference may be in part be due to the difference in paradigm employed in Study 2.2 compared to work by Balas and Conlin (2015), and other related research (Hicket et al., 2019; Papera & Richards, 2016). Whereby work conducted in Study 2.2 required participants to ignore distractor stimuli in order to complete a primary task, visual search paradigm have required discrimination, which is linked to greater N1 amplitudes (Mangun & Hillyard, 1991).

Interestingly, the same paper (Balas & Conlin, 2015) reported differences in the 250-400ms range which were not examined due to a lack of a priori hypotheses. In Study 2.2 the a priori hypothesis was specifically to investigate the N2 (246-346ms) range. This overlap in difference does suggest that image synthesis techniques are a viable method for investigation levels of inhibition both in the N1 and N2 range. The findings also have implications for using real-world images to investigate levels of inhibition. Classic attentional theories have proposed that processing of synthetic, basic stimuli should be much more efficient when compared to images that resemble more natural scenes, as processing of complex stimuli requires serial application of attention in order for comparison of templates (Treisman & Gelade, 1980). However, work in Study 2.2, in addition to research isolating neural evidence of sensitivity to targets in the N1 range (Balas & Conlin, 2015; Fabre-Thorpe, Delorme, Marlot, & Thorpe, 2001; Vanrullen & Thorpe, 2001), does suggest that processing of natural scenes and their violations are equally as efficient.

The differing amplitude in the N2 range in response to image type also falls in line with evidence demonstrating a role for quick distractor suppression in studies that use more natural stimuli (Hickey et al., 2019; Seidl, Peelen, & Kastner, 2012).

This in turn has implications for research investigating the role of the consistency effect in images (see Kutas & Federmeier, 2011). Research has implicated the N300 and N400 in being sensitive to low-level summary statistics of textures, as the component was elicited when incongruent objects were places over such scrambled textures. Activity in the N300/N400 range has been linked to this consistency effect, with activity seen for semantically inconsistent objects (Mudrik et al., 2010; Mudrik et al., 2014; Võ & Wolfe, 2013). Results from Study 2.2 therefore, suggest that this consistency effect can also manifest itself through increased level of distractor inhibition, where if levels of inhibition were equal throughout manipulations of image distortion then it could be argued that identification of the distractor occurred after inhibitory processed. The visual system is capable of accurately judging features such as orientation of objects without serially allocating attention to each (Ariely, 2001). Additionally, the segmentation of an image is not required to extract a semantic gist, such as the degree of 'naturalness' (Green & Olivia, 2009; Joubert, Rousselet, Fabre-Thorpe, & Fize, 2009).

Therefore, the increase in distractor inhibition to high violated distractors compared to natural does demonstrate that individuals are able to activate scene knowledge which have a role in top-down predictions for semantically related stimuli (Bar 2004; Trapp & Bar, 2015). More broadly speaking, the results of early neural differences caused by violations in distractors provide more support for matching models of object identification, as opposed to functional isolation models. Matching models (Bar, 2004) predict that when individuals are shown natural scenes, the gist is extracted rapidly and compared to existing schemas, which are activated in early perceptual processing. This process produces slower response times and lower accuracy, and while only the latter was observed in Study 2.1, the quicker response times to violated images may have been a product having yet to group violated images into a high or low category.

Simultaneously, the early neural differences found in Study 2.2 oppose the functional isolation model (Hollingworth & Henderson, 1999), which proposes that behavioural measures such as poorer accuracy and slower reaction times instead are a product of post-perceptual processes. Scene and objects must be processed first in isolation of one another, where after processing is complete, the semantic relations between the two influences performance (Hamm, Johnson, & Kirk, 2002). This model consequently only predicts later neural activity for consistency effects, not consistent with results observed in Study 2.2, furthermore, differences in the N2 range were observed in occipital areas. This is suggestive of an early visual area input, supported by fMRI data showing contextual effects in such areas (Brandman and Peelen, 2017).

Results from Study 3.1 attempted to regulate image manipulation in a more systematic manner, and whilst some differences did emerge across working memory capacity groups, implications from this study are speculative due to the lack of power and contralaterality, and overall lack of significant effects. The study does however contribute to the argument that research into inattentional blindness and working memory capacity can be bought back to stimuli that aim to emulate real world instances. Whereby research into inattentional blindness began with such examples of an unexpected gorilla in a counting task (Simons & Chabris, 1999), or even more impactful situations as not noticing a weapon when pulling over a driver (Simons & Schlosser, 2015). Whilst these examples emulate where inattentional blindness actually has an impact, they lack the level of experimental control to investigate and isolate neural correlates. Work in both Chapter 2 and 3 have contributed to progressing this field further.

Working Memory Capacity and Object Tracking

Results from Chapters 4 and 5 carry implications for two broad areas; theories of MOT, and whether individuals flexibly change strategy to achieve performance when tracking over a gap, in relation to the use of motion or location information. In regard to theories of MOT, results here begin to provide evidence for the flexible allocation of resources in MOT (Alvarez & Franconeri, 2007). Study 5.2 demonstrated a correlation between working memory capacity and tracking accuracy, suggesting that the ability to perform the MOT task accurately may rely on capacity measures when being asked to track beyond such limits. This is most readily explained by flexible allocation of resources, where the ability to accurately perform the task is achieved by high working memory capacity participants due to the greater resources at their disposal. Although effects across the three studies in Chapter 5 were not always replicated, the lack of consistent change in CDA amplitude from tracking to masking periods across trial nature has implications for tracking research. The lack of consistent change is suggestive that individuals were most probably employing a post-probe approximation strategy in order to estimate target locations. Given that amplitude did not show increased levels when participants were required to predict trajectories compared to when they were required to maintain representations is suggestive that the latter was being performed in both masking variations.

Results in this thesis therefore suggest that whilst instances where participants use motion information are observed when target load is low (Fencsik et al., 2007) or when observed trajectories are predictable (Howe & Holcombe, 2012), here the strategy for post-probe approximation using location information was used regardless of load and furthermore regardless of working memory capacity. Whilst extrapolating trajectories is a viable strategy for object tracking, the additional use of resources that it may require (Flombaum et al., 2008), means that even when explicitly required, a post-probe approximation carries less demand for resources and is employed preferentially. Throughout the three studies in Chapter 5, differences emerged across levels of working memory capacity, whereas contrasting trends were observed across working memory capacity in Studies 5.1 and 5.2, the differences in change in Study 5.3 does have implications for the consistency of applied strategy in object tracking. Research has proposed that there is a difference in limit for the number of items tracked per participant (Oksama & Hyömä, 2004), and this is supported by differences in tracking capacity observed in the MOT (Drew & Vogel, 2008).

However, the difference in change across the experiment for low but not high working memory capacity participants is similar to findings that low working memory capacity individuals change strategy due to capacity limits (Weimers & Redick, 2018), but the first to demonstrate so in the MOT task. While results must be taken alongside the notion of a lack of contralaterality, they are still suggestive of trends emerging. This concurrently has links to more general research in attentional control (Braver, 2012; Braver et al., 2007). It may be the case that limited resources are indeed allocated flexibly to targets (Iordanescu et al., 2009), but is more likely to occur when capacity limits are more restricting, for instance through the masking period. The results that suggest the low working memory capacity individuals change in CDA amplitude over experiment time does fit well with original cognitive control research, where it is suggested that high working memory capacity individuals exhibit proactive control as the standard level of processing (Redick, 2014). This may translate to the lack of change in CDA amplitude for high-capacity participants in Study 5.3, as they consistently employ an efficient tracking strategy as standard.

Results also have implications for the perceptual grouping theory of MOT (Yantis, 1992), where it seems that some perceptual grouping may have influenced CDA amplitudes. Amplitudes were consistently below the corresponding number of targets that were assigned. Although this has been observed in related literature (Drew & Vogel, 2008; Drew et al., 2011), it is suggestive that participants may have been grouping target under larger loads in order to meet task demands. CDA amplitudes in Study 5.2 for the supra-capacity display are similar to original supra-capacity MOT tracking (Drew & Vogel, 2008), where the amplitude in five target trials shows a decrease relative to other loads. It is possible that perceptual grouping may have been employed as a strategy overall, although research has shown CDA amplitudes to be equal over varying distances (Drew & Vogel, 2008), where grouping would be advantageous.

Lastly, the analysis undertaken on the combined dataset demonstrates that CDA amplitude reflects a robust association with the target load in MOT. The re-emergence of the three-way interaction does tentatively suggest that a difference in working memory capacity may be associated with different levels of CDA amplitude. However, given that in Study 5.2 a significant correlation between working memory capacity and CDA amplitude was observed in the direction hypothesised, it may be that the nature of working memory capacity on tracking multiple objects with a trial-gap may only be unveiled with such a sample size being required to also track supra-capacity displays.

Multiple Object Tracking and the Contralateral Delay Activity

Results from Chapter 5 also have implications for the use of CDA in tracking. Previous research has suggested that the CDA carries potential to investigate background prediction mechanisms (Drew et al., 2012), but here behavioural demands resulted in participants not exhibiting a change in CDA from tracking to masking periods. Although an argument could be made that the consequently the CDA would not be sensitive to an explicit predicting strategy, CDA amplitudes have been observed as greater when tracking compared to maintaining stationary representations (Drew et al., 2011). The assumption is made that in order to therefore predict trajectories, participants would have to mentally track targets over the trial gap, which would result in a CDA amplitude similar to actual tracking.

In Chapter 5 no differences across tracking and masking periods were observed. However, more importantly, no differences were observed across trial nature and trial phase. This is suggestive that whilst the CDA amplitude may show potential to investigate background predictive mechanisms and online changes to tracking (Drew et al., 2011, Drew et al., 2013), here participants were not employing a mental tracking strategy. The CDA component remains a useful tool in delineating the use of motion and location information in regard to tracking objects, and work in this thesis has proven that the use of the component can be important in investigated whether differences emerge as a product of individual capacity limits or not.

Wider Relevance

The results throughout this thesis also carry a number of wider implications. Firstly, the propensity to miss items in our visual fields carries important ramifications for situations where vigilance is required, or when the unexpected nature of stimuli carries importance. Instances have been noted when during vigilance tasks inattentional blindness has been the cause for airway traffic accidents (Green, 2003), or influencing eye-witness accounts of crimes that occur within close proximity of the individual (Chabris et al., 2011, see also Simons and Schlosser, 2015). Work in Chapter 2 however found no link between working memory capacity and inattentional blindness, therefore this lack of link weakens the case for interventions such as working memory capacity training for such jobs. Given that the opposing view to the resource-based hypothesis is that inattentional blindness remains a more stochastic phenomena, which can be influenced by parametrical factors such as load, work in Chapter 3 contributes to the same position. It is therefore of importance to monitor the overloading of cognitive load in such roles and advise against such overloading in activities that carry increased danger such as driving.

Although no link between inattentional blindness and working memory capacity was established in this thesis, work did suggest at differences across capacity scores and tracking strategy. While this has specific implications for real world roles, which will be discussed, it also carries a number of overarching points, such as with vigilance tasks. For instance, while working memory capacity may not determine the propensity for inattentional blindness, lower working memory capacity individuals may in differ in tracking strategy (Chapter 4) and performance when being required to track beyond their limits (Chapter 5). However, work in this thesis tentatively suggests that lower working memory capacity individuals change approach with time on task. This was only recorded at the neural level, so it is unclear whether time on task also influences tracking accuracy in the same way it influences neural signatures (Chapter 5). However, work still translates to roles that require multiple object tracking, and that given time on task can compensate for initial inefficient cognitive control strategy.

The suggestion of change in cognitive control when tracking also has wider implications for working memory applications in contexts such as education. Given work in this thesis has illustrated differences in approach across working memory, a complimentary view should be taken that educational materials should be adjusted to facilitate effective learning for different working memory abilities (Cowan, 2014). This could translate to providing information at an earlier stage to individuals, to allow those with lower working memory capacity to make pre-existing links, in order to free up limited resources when information has to be revisited. Work in this thesis has shown that tracking accuracy is inferior the lower the working memory capacity, when being asked to track beyond limits (Chapter 5). Therefore, the approach to allowing lower capacity individuals to offload cognitive demands, through for instance creating pre-existing links, would help to aid performance.

6.4 Limitations and Future Research

Inattentional Blindness

An inherent flaw that has previously been discussed in this thesis is classifying participants on the basis of a one-trial exposure. White and colleagues (2018) put forward the argument that individuals that are excluded from studies on the basis that the unexpected change in an inattentional blindness screening task was not consciously perceived in the full-attention trial actually show an extreme form of inattentional blindness. In total, only a single participant was excluded in Chapter 2 due to the inability to perform the task, consequently, the issues with excluding participants on the full attention trial do not strictly apply. Whilst the individual that was excluded could have also been exhibiting inattentional blindness, exclusion based on ambiguity to the probes was implemented in order to have a clear-cut classification.

However, the issues with the one-trial exposure still exist and will remain so. Although more recent work has discussed the phenomenon as the propensity to neglect visual stimuli as opposed to a concrete trait (Papera & Richards, 2016), it is difficult to quantify whether the instance in which the inattentional blindness task was shown correctly reflects the probability of that individual to neglect the unexpected change. This core limitation was why work after Chapter 2 addressed capacity limits and the manifestations of such limits, whilst discussing potential links to the inattentional blindness paradigm as opposed to strongly proposing them as underlying casual mechanisms.

Image Manipulation

Scope for further research within the area of image manipulations carries links to a number of research areas, however, in order to do so methodological restrictions would need to be addressed. Firstly, the process of image quilting could have been made more efficient, by accommodating work that built upon the original Efros and Freeman (2001) procedure. Long and Mould (2007) introduced a method where the options for the boundary cut made across blocks are stored in an order with the option that requires the least amount of cost first. Another potential area for improvement would be to implement the search strategy for aligning blocks of the texture demonstrated by O'Brien and colleagues (2004). Another area that could be improved upon in is the control or quantifying of low-level image statistics. Research into the N300/N400 by Lauer and colleagues (2018) used a model of texture synthesis that extracted a number of low-level statistics from images before generating stimuli. First-order statistics extract luminance and spectral information from the source image, second-order statistics summarise the autocorrelation of the image, magnitude correlation assesses repeated image structures over position and scale, and lastly, phase statistics which are linked to three-dimensional appearance. These statistics are then compared and altered with Gaussian noise until statistics match to the source image.

However, in the image quilting process such low-level image statistics were unaccounted for. Instead, an error term computed by the process was considered sufficient enough. This error term was a measure of the minimum distance between overlap regions of blocks that were quilted together, where a larger error term translated to a greater distance that the boundary cut had to be made over. Scope for further research, and consequently further implementation of image quilting in research areas within this thesis, should therefore involve the manipulation of low-level statistics to control for saliency. Contrastingly, whilst image quilting carries scope for future research in terms of application, for instance in the flanker paradigm to assess inhibition differences, the autoregressive method used in Chapter 3 may not maintain semantic information in the same way that image quilting does. Whilst low-level statistics again are not accounted for, here the patches may more resemble the saliency patches akin to work investigation more bottom-up processes (Papera et al., 2014; Papera & Richards, 2016). As the process relies on existing image statistics, which in this instance were converted to greyscale, it may not have the capacity to be used to investigate complex, semantic processes.

Further research should make use of image quilting by adding to two aspects; firstly, controlling for low-level statistics so that more robust measures such as saliency can be computed and compared. Secondly, the algorithm itself could be improved upon in order to better isolate the quilting process. By doing so, research could combine the image quilting process with a more controlled, systematic manipulation. Currently the image quilting method produces a new texture from a source image, however, by limiting the output to a gap in the image, saliency can be controlled for as the manipulation is more local, as opposed to the global distribution of error seen in Chapter 2. This would open up further research on naturalistic search (see Hickey et al., 2019), where image quilting could be used to manipulate textures within complex images that contain other stimuli, and not within images that just contain textures. The creation of such stimuli would help to achieve aims set out in this thesis: to assess sensitivity differences across working memory capacity in stimuli that effectively simulate our visual experience in everyday life. This would also allow for greater translation of experimental effects to jobs or activities that carry a requirement for vigilance.

Multiple Object Tracking

As mentioned previously, future research should look to investigate the level of influence attentional control strategies have on multiple object tracking. Research has linked reactive control to lapses in attention (Unsworth & McMillan, 2014), where the lapse in attention may cause a knock-on effect in ongoing task requirements meaning that participants have to rely on reactive measures as opposed proactive. Research can build upon the suggestive results in Chapter 5 to investigate whether this phenomenon is a contributing factor in the tracking of multiple objects, and specifically whether it is therefore a contributing factor to the incidence of inattentional blindness. Such research will also contribute to the findings that a propensity exists for lower working memory capacity individuals to change strategy over the course of the experiment (Weimers & Redick, 2018).

Such findings would aid our understanding for not just performance in MOT tasks, but in whether low working memory capacity individuals can actively encourage strategy use to compensate for their limitations. Working memory capacity has been implicated in roles for simple attention tasks (Kane et al., 2001), to more complex, compound tasks such as reasoning and problem solving (Engle et al., 1999), and to functioning with everyday tasks (Nagel & Lindenberger, 2015). Furthermore, with capacity being a predictor of cognitive training efficacy in older adults (Matysiak, Kroemeke, & Brzezicka, 2019), the notion that individuals with varying working memory capacity perform tasks differently would help to tailor training strategies in application for fields such as cognitive training or education.

Working Memory Capacity

Recent research has outlined the importance to investigate the approach that individuals employ in order perform working memory tasks (Pearson & Keogh, 2019). Specifically, research investigating strategy use in tasks that are not visual based have documented individual differences in the neural activity elicited (Miller et al., 2002; Miller, Donovan, Bennett, Aminoff, & Mayer, 2012). Verbal requests for strategy use have also exhibited differences in approach, with participants employing an approach to compare current visual stimuli with a previously encoded template (Berger & Gaunitz, 1979), or a creation of mental images in the retention interval (Keogh & Pearson, 2014). The use of mental imagery may then be an influencing factor in the debate of capacity constraints, and work done in this thesis.

Given the neural overlap in visual working memory and mental imagery demands (Albers, Kok, Toni, Dijkerman, & de Lange, 2013; Kosslyn & Thompson, 2003; Kosslyn, Thompson, Kim, & Alpert, 1995), it may be the case that capacity limits can be circumvented through the strategy employed for the task. Indeed, results from Chapter 5 do suggest at differences across working memory capacity, this is more pertinent given that whilst differences did emerge over CDA amplitude, accuracy of the task did not depend on the capacity of individuals, when targets were within limit. Although recent research has found that visual imagery interference was only an interfering factor for participants coined as ‘good imagers’ (Keogh & Pearson, 2014), again suggesting that strategy use would not ubiquitous across participant samples, in line with results from this thesis. Future research should continue to address the divergent use of strategy use that is dependent on working memory capacity. Building upon the suggestive trends observed in this thesis, such work will help to elucidate whether the capacity limits established, whether a flexible resource or a discrete model, are subject to influence from visual cognitive strategies.

6.5 Concluding Remarks

In conclusion, this thesis has offered novel methods to investigating existing debates in psychological research, such as the inattentional blindness dichotomy, with aims to bring investigations more in line with everyday experiences. The first two chapters made inroads in using systematic, photo manipulating algorithms to assess neural sensitivity, and whether such sensitivity was dependent on working memory capacity resources. The latter two chapters then turned to investigate what was identified as potential confounding factors in both research studies conducted in this thesis, but also existing research in inattentional blindness. These latter two chapters sought to identify potential divergent tracking strategies that may influence tasks such as the inattentional blindness screening task. This was done through both purely behavioural measures, but also attempting to link behavioural performance to divergent neural patterns. Whilst results were not conclusive, results in this thesis have been successful in making inroads to new, more effective methods, and showing potential differences across working memory capacity that may be undiscovered if behavioural performance alone is only considered.

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