# The Effects of Cognitive Load, Social Objects, Non-social Objects and Adhd-like Traits on Visual Attention

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# Declaration

I declare that this thesis, 'The Effects of Cognitive Load, Social Objects, Non-social Objects and Adhd-like Traits on Visual Attention', represents my own work, except where otherwise stated. None of the work referred to in this thesis has been accepted in any previous application for a higher degree at this or any other University or institution. All quotations have been distinguished by quotation marks and the sources of information specifically acknowledged.

Submitted by Astrid Priscilla Martinez-Cedillo

Signature of Candidate:

Date: 02 – August -2021

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*To Luka.*

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## Co-Authorship statement

I am the main author on all the work presented in this thesis. The study from chapter 7 is a collaboration with Jessica Dawson, to which I have contributed equally as a first author. This study has been included as the results are relevant to the aims of the current thesis.

## Open Science statement

Experiments 3 to 9 were pre-registered and the data will be available https://osf.io/qsva4/

# Abstract

The current thesis examines the effects of cognitive load, social object, non-social object and ADHD-like traits on visual attention. This thesis reports (Experiment 1 and 2) a modified version of Lavie et al, (2004; 2005) and confirmed that increased memory load disrupted performance in the classic flanker task, but not in the singleton. Experiment 3 uses the same manipulation of WM load to probe attention during the viewing of complex scenes. Experiment 4 and 5 examines the effects of visuospatial WM on different presentations: sequential and simultaneous. These experiments compare the extent to which increasing WM load would change the pattern of viewing of the physically salient and socially salient objects while also investigating differences in ADHD traits. Experiment 6 examines the effects of instructions on the image-viewing task by restricting areas such as: social and non-social. Experiments 7 and 8 examines the effects of occluding the eyes in a conversation in traits of ADHD and ASD (low vs high). Experiments 9 examines the relationship between working memory components (maintenance and distractor processing) and ADHD traits within the general population. This thesis discusses their results based on visual prioritisations (social, high and low salience), cognitive load and the heterogeneity of ADHD and their comorbidities. Taken together these results provide interesting implications in eye movements behaviour, in the understanding of individual differences and in the underlying cognitive abilities.

# Chapter 1
# General Introduction

## 1.1 Overview

*Picture yourself talking to a friend in a busy place such as Piccadilly Circus or Time Square NYC. Whilst talking to your friend, you are trying to prevent yourself from looking around, however; the billboards with highly salient features around the area seem to be interfering with where you are looking (your friend's eyes or mouth). Additionally, you are trying to remember the location of a nice coffee shop near the area. After some time, your friend suddenly asks you whether you agree or not in the conversation. But how would you be able to remember the conversation while you were trying to remember that nice location and at the same time avoiding those highly salient billboards?*

Some people will be able to keep the conversation going, but some others not. Under this example, we need cognitive resources to stay focused on relevant stimuli while avoiding distraction and to visually attend to the speaker. Load Theory suggests that increased cognitive load limits our capacity to avoid irrelevant stimuli (Konstantinou & Lavie, 2020; Lavie et al., 2004). In addition, attentional mechanisms (stimulus-driven and goal-driven) are fundamental to understanding how we focus on stimuli in complex situations. 'Where' and in 'what order' people look at different stimuli within a scene, as illustrated in the above example, is currently a matter of discussion in visual attention research. If one intends or aims to look at a specific area of interest; this mechanism is referred as top-down (Awh et al., 2012; Beck & Kastner, 2009). But, if the properties of the object/area (i.e., the highly salient billboards) drive our attention regardless of our expectations or intentions; this mechanism is referred to as bottom-up or stimulus-driven (Itti & Koch, 2000; Theeuwes, 2010). The difficulty of avoiding distractors and/or concentrating on what people are saying are two of the key symptoms of

Attention Deficit/Hyperactivity Disorder (ADHD; APA, 2013). ADHD is measured as a discrete diagnostic entity and as a continuous trait within the general population (Crosbie et al, 2013). Cognitive and social impairments have been reported in those with high traits of ADHD and within the disorder itself (Alderson et al., 2013; Barkley, 1997; Crosbie et al., 2013; Faraone, 2000; Forster et al., 2014; Friedrichs et al., 2012; Kim et al., 2014; Nigg, 2001; Sergeant et al., 2003; van Ewijk et al., 2014). Given these impairments, ADHD seems to be a disorder with the potential to help us understand visual and cognitive behaviour in different scenarios, for instance by leading to a different pattern of looking to specific areas within a scene.

The current chapter is a literature review highlighting the key studies that guided the formation of the initial research hypothesis. The experiments in this dissertation have been designed to understand cognitive load, the allocation of visual attention, and how ADHD traits within the general population affect these mechanisms. The first section of this chapter describes visual attention. The second section of this chapter describes cognitive load and distractor avoidance. The last section will describe the effects of Attention Deficit Hyperactivity Disorder (ADHD) traits on visual attention, cognitive load and distractor avoidance.

## 1.2 What factors capture visual attention?

Visual attention may be defined as the use and the prioritization of one region of the visual field over other regions of the visual field (Henderson, 1992). However, we may find ourselves looking more to areas with high luminance even though we have no intention to attend to these areas. These stimulus properties enter first to our retina to determine visual guidance and selection (Bundesen, 1990). Attention has been suggested to be the interaction of "top-down" and "bottom-up" factors which contribute to determining which parts of the visual field are prioritised (Awh et al., 2012; Desimone & Duncan, 1995; Duncan & Humphreys, 1989; Henderson, 1992; Katsuki & Constantinidis, 2014; Theeuwes, 2010; Treisman, 1980). Top-down factors relate to a participants' goals and expectations, whereas bottom-up factors relate to physical properties of the stimuli (Beck & Kastner, 2009; Flechsenhar et al., 2018; Hopfinger et al., 2000; Itti & Koch, 2001; Theeuwes, 2010). Although bottom-up and top-down attentional deployment originate from different anatomical subsystems (Katsuki & Constantinidis, 2014), the frontoparietal network mediates both attentional processes (Behrmann et al., 2004; Katsuki & Constantinidis, 2014).

Top-down attentional capture is subserved predominantly by frontal brain areas or higher brain areas (Hopfinger et al., 2000; Miller & D'Esposito, 2005). This mechanism involves many brain areas: the anterior cingulate cortex, descending pathways covering the neocortex and the thalamic nuclei (Gilbert & Li, 2013; Miller & D'Esposito, 2005). However, there is evidence that some brain areas are activated in the parietal lobe when individuals are instructed to complete a shifted attentional task. These areas are the superior parietal lobule (SPL) and the praecuneus (PC) (Behrmann et al., 2004).

Bottom-up attentional capture mediated by stimulus salience is subserved predominantly by the posterior parietal cortex (Behrmann et al., 2004). This process is initiated by basic visual processing via the visual cortical pathways, that is; from the primary visual cortex (V1), feed-forward signals ascend to multiple cortical areas and continue into two major pathways: a ventral pathway (which processes objects and is features-related) and the dorsal pathway (which processes spatial and is movement-related) (Lamme & Roelfsema, 2000; Miller & D'Esposito, 2005; Miller & Buschman, 2013; Motter, 1993). Furthermore, the superior colliculus and the frontal eye fields are also suggested to be involved in this type of attentional deployment (Bollimunta et al., 2018; Herman et al., 2020). Both top-down or bottom-up influences represents a continuous interaction within sensory information processing, based on feedforward and feedback (FB) connections as represented in Figure 1 (Gilbert & Li, 2013).

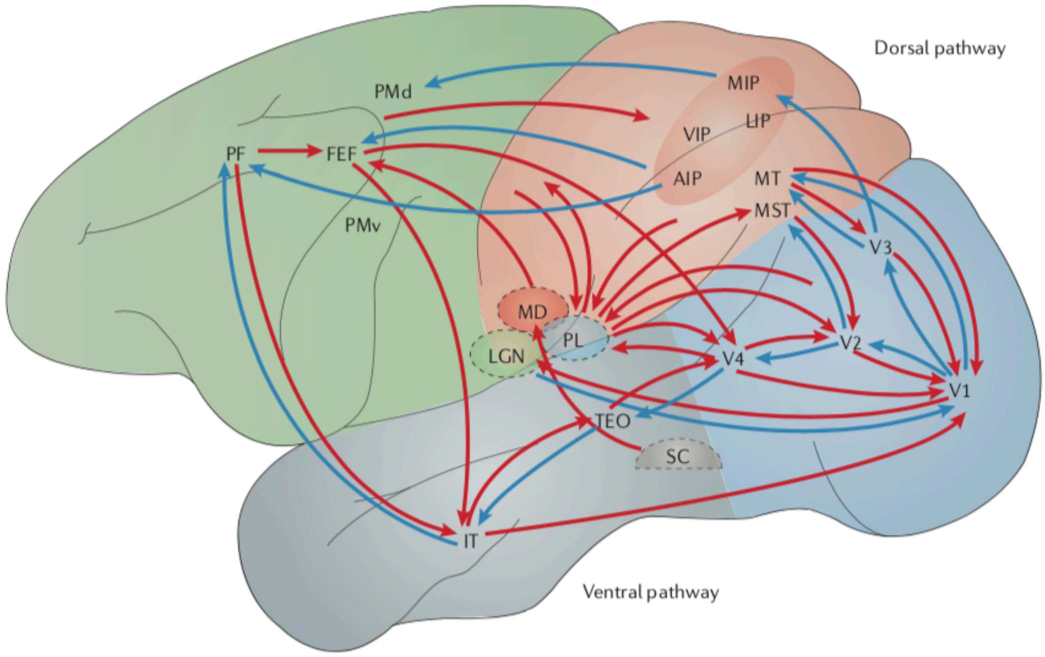


*Figure 1 The feedback pathways in visual information processing.*

*The blue arrows represent the visual cortical pathways transporting visual information. This information enters the primary visual cortex (V1) and receives subcortical input from the lateral geniculate nucleus (LG). The feedback (FB) connections sparse along the ventral pathways through the temporal lobe, parietal cortex and prefrontal cortex. The red arrows represent the feedforward connections as reciprocal connections to the FB. This figure was taken from* (Gilbert & Li, 2013).

Early research on visual attention has shown that searching for an element that differs in features, colour or orientation, can be easily processed without the need of attending to each of the elements within the stimulus (Desimone & Duncan, 1995; Duncan & Humphreys, 1989; Theeuwes, 1991; Treisman, 1980). For instance, in the singleton paradigm used in Theeuwes, (1991) which has been extensively used to examine the distractor-cost. Participants were presented with a display that contained a target singleton (line segment) among other low-salience distractors. In some trials the target was the only singleton in the display, but in others the distractor had a unique colour. Results showed slower responses to target in the presence of the salient distractor over the absence. Theeuwes suggested that attention was initially misallocated to the distractor as a consequence of its salience. In this effect, if the irrelevant colour distractor is presented similar to the target, there is no effect on search anymore (Theeuwes, 1991). This singleton phenomena has been examined in artificial paradigms  (Donk & van Zoest, 2008; Theeuwes et al., 2003; van Zoest et al., 2004; van Zoest & Donk, 2005). Van Zoest and Donk (2005) used a search display to test the orientation and colour with targets and distractors. They found that salient items capture earlier fixations. Furthermore, it has been suggested that the salient effect drives eye movements only within a short time period (Donk, & van Zoest, 2008).

## 1.3 Computational models of capture

Many models have attempted to incorporate top-down and bottom-up influences into attention selection. For instance, Borki, Sihite and Itti, (2012) made an exhaustive comparison of 35 state-of-the-art models over 54 patterns. Results showed commonalities between stimuli, but also some concerns in regarding the datasets. In this thesis, I only focus on the most prominent model by Itti and Koch (2001). This explicit model suggest that salient features are most likely to attract attention based on computational architecture. This model suggests three features maps (intensity, colour and orientation) combined into a single map (see Figure 2). In the saliency map model  (Itti & Koch, 2000), image inputs come from early visual processing which facilitates visual deployment by scanning the most prominent feature in a scene.

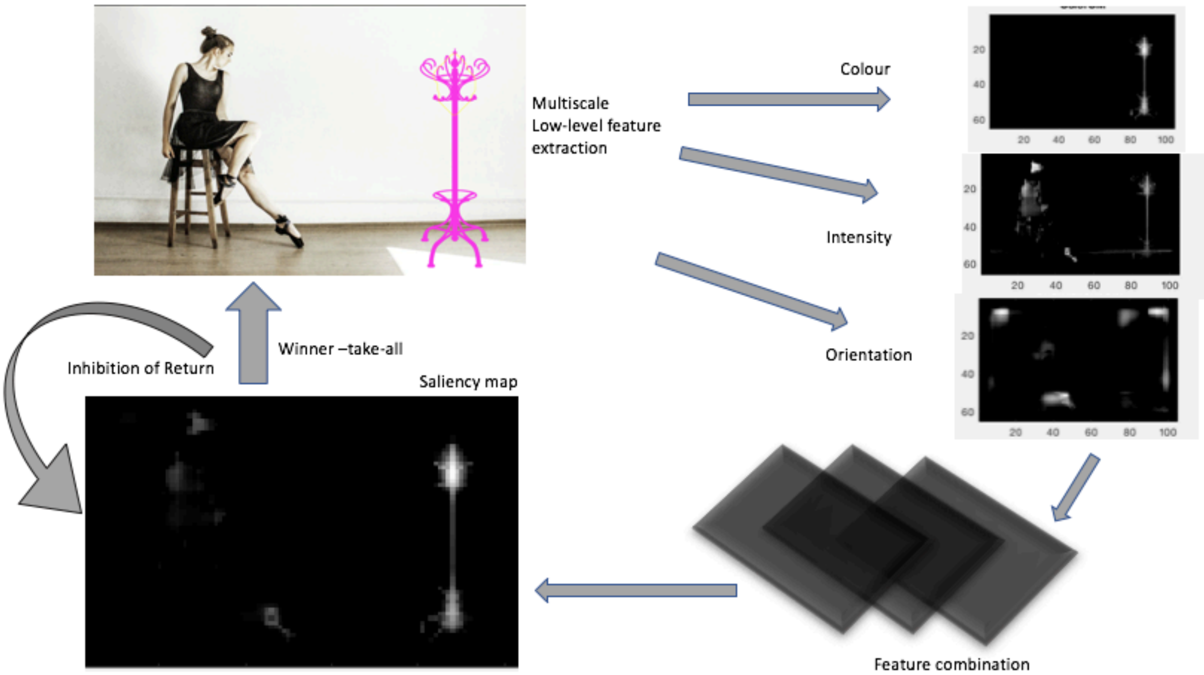


*Figure 2 Schematic representation of how attention is driven in a bottom-up manner. The image input was used in the Experiments conducted during the research of this thesis. This image contains a high salient non-social object. The saliency Toolbox from Walther and Koch, (2006) was used to obtain the salience maps.*

In this example the scene ‘input image’ is decomposed in low-level features (colours, intensity, orientation, etc). Neurons encode for spatial contrast in each feature map. Then, neurons in each feature map compete for salience. After competition all the features are combined into a single map, which topographically encodes for saliency. Two processes are crucial here: (1) the winner-takes-all network detects the point of highest saliency at any given time, (2) Inhibition of return supresses the last attended location from the saliency map. The saliency map is sequentially scanned by attention via the winner-takes-all network and the inhibition of return. But where does this salience map representation take place in the brain? It has been suggested multiple brain areas such as: the frontal eye fields (FEF)

(Bollimunta et al., 2018), the lateral intraparietal area in the posterior parietal cortex (Behrmann et al., 2004; Chambers et al., 2004; Wilterson et al., 2021), and the superior colliculus (Bollimunta et al., 2018). Image-viewing studies have been typically analysed using such properties by comparing the time and location of fixations to a saliency map. Interestingly, only minimal effects in early fixations have been reported, which are mostly overridden by task demands (Foulsham, & Underwood, 2007; Underwood & Foulsham, 2007; Underwood, Foulsham, van Loon, Humphreys & Bloyce, 2006). Particularly, in a previous study by Underwood, Foulsham, van Loon, Humphreys and Bloyce, (2006) pictures of an office scene were used to examine this effect by manipulating the images with high and low salient areas. The authors performed two experiments: inspecting the picture and searching for a target. Their outcomes demonstrated that visual attention is indeed driven by the salient effect in earlier fixations, however; when participants were required to search for a target, this effect was no longer found (Underwood, Foulsham, van Loon, Humphreys & Bloyce, 2006). Anderson, Ort, Kruijine, Meeter, and Donk (2015) increased and decreased the saliency of a series of natural scenes during an inspection and searching task. The authors found an effect on salient areas present early on time and in short-latency saccades.

Some of the caveats that the saliency map model has, is the fact, that it does not account for people within the scenes. Having social elements in a scene is crucial, since we are constantly interacting with people either in a virtual or natural manner. Another caveat is that cognitive load might affect our visual selection. For instance, we might not be able to attend to the traffic signals if we are talking with a friend in the phone. The following sections describe studies measuring eye movements in order to understand the effect of such factors (social and cognitive) on visual attention.

## 1.4 How does social information capture our attention?

Vision research has demonstrated that people naturally tend to look at people (End & Gamer, 2019; Flechsenhar et al., 2018; Foulsham et al., 2010; Laidlaw et al., 2011; Laidlaw & Kingstone, 2017; Vo et al., 2012). For instance, Flechsenhar, Rosler and Garmer, (2018) asked participants to look freely or under a gaze-contingent condition to social and landscape pictures. The gaze-contingent condition allows the displays of specific areas of the screen depending on where the viewers are looking. Results revealed more frequent fixations and closer in time to social areas than non-social areas regardless of the conditions. Thus, indicating that there is a bias to social areas. In the same line, a recent study (End & Gamer, 2019) showed that early fixations are biased to social areas within a naturalistic scene. In this study, the authors asked participants to look freely or to specifically look at the social area. Their outcomes demonstrated earlier fixations to the social area when task demands were required (look at the person) in comparison to the free viewing condition. These results suggest that social capture appears early on time and is not affected by tasks demands.

Laidlaw, Foulsham, Kuhn & Kingstone, (2011) asked participants to await whilst there was a person in the same room either on a video screen or physically presented. This study addressed the question of whether someone's attendance either virtually or physically might affect social attention. Results showed more fixations to the video than the person physically present. They concluded that this effect can be due to the activation of social norms, thus impeding to the participant look directly for a long time to the person physically presented. That might be the case for some of us who feel more comfortable to be present virtually than in a room with an audience. While social norms can influence in our eye behaviour, social status plays a role to direct our behaviour, as well. For instance, Foulsham, Cheng, Tracy, Henrich and Kingstone, (2010) asked participants to look at a series of videos of people in a conversation. The outcomes brought evidence that observers tend to look more to those participants categorized as high-status targets (the status was determined by a battery of judgments) in comparison to the medium or low-status targets. Here the eyes were the most frequently fixated area following the rest of the face and the body. They also examined whether eye movements of observers were sensitive to the speech of the participants, the results showed that observers tend to have more fixations to those who spoke the most in comparison to the others.

The eyes have been widely studied in social attention research (Foulsham, Cheng, Tracy, Henrich & Kingstone, 2010; Laidlaw & Kingstone, 2017; Vo, Smith, Mital, & Henderson, 2012). The importance could be due to emotional and intentional information that we can obtain from looking at the eyes (Birmingham et al., 2009). For instance, Vo, Smith, Mital, and Henderson (2012) used video clips of a pedestrian under two conditions: voice sound and mute. The authors studied whether specific areas of the face are biased to be looked at when someone is speaking. Their outcomes demonstrated that participants looked more to the eyes in both conditions with sound and mute. Participants looked more at the mouth in the voice sound condition. Furthermore, Laidlaw and Kingstone, (2017) demonstrated that looking at someone's eyes is not a voluntary process. In the study three conditions were tested: (1) do not look (DL) at the eyes (2) DL at the mouth, and (3) free viewing (FV). They reported that in the FV condition participants tend to look longer to the eyes. In the DL eyes condition participants made more errors (i.e., more fixations to the eyes area), compared to the DL mouth condition. The DL conditions are interesting because avoiding specific features reveal the mechanism controlling gaze behaviour than those underlie attention selection. Collectively, these results suggest that there is a tendency to look at social areas of a stimuli i.e., a person or people within a scene., specifically we tend to look at the eyes.

## 1.5 The implications of expectations and goals in visual attention

Interest has grown in how information is given to perform a task that can affect visual deployment. For instance, when someone asks you to "look for a blue pen on your desk". You have now an explicit indication (on your desk) which is controlled by the top-down mechanism. In that sense, you need to retrieve where you allocate your pens, and whether you have or not a blue colour - such deployment of attention will take some time to perform; it comes from an explicit indication. On the other hand, when specific features in your visual field attracts attention (for example: a blue pen among black pens) - such deployment of attention will be effortless, automatic and without any specific indication to look for the blue pen. Interestingly, however, there is an ongoing debate on whether the relevance should be shared between these two attentional mechanisms. A proposed model argued that attention is not always driven by goals of physical properties of the stimuli, rather are driven by previous experience or history (Awh et al., 2012). Considering the previous example, this account claimed that selection history is learned by implicit and explicit relevance, therefore; this learning will have an effect on future selection unrelated to top-down goals or the physical salience of items (Awh et al., 2012; Theeuwes & Failing, 2020). The evidence provided to the selection-history relies on a bottom-up bias with a difference between an explicit or implicit learning, Egeth, (2018) has commented that the selection bias is better explained as it emerged from a top-down mechanism with an implicit or explicit learning.

Benoni and Ressler, (2020) have suggested that these attentional mechanisms should be studied as a spectrum. They suggested two different scales: (1) named as the volitional scale: that comes from voluntary or explicit to involuntary or implicit relevance (2) named as the temporal scale: that comes from temporary or specific relevance to permanent or general relevance. Under this approach the effects of attention should be understood across these two different scales. Recently, Luck et al (2021) have published a review in which join together different theoretical frameworks. They explain how attention can be prevented and/or facilitated under different circumstances. The three theoretical frameworks agree that singletons can be suppressed if none of the elements is high in salience but only at small set sizes. However, it is not clear yet whether the ability to avoid visual distraction is due to learning (either implicit or explicit).

## 1.6 How do we perceive or avoid distractors in visual attention?

In this section, I describe previous research to provide evidence of the different stages of attention selection. Thus, providing a better understanding on the how attention is allocated recalling the first example of talking to your friend in a busy street. Early research on perceptual load claimed that early selection is possible only when the processing of relevant information is sufficiently high or exceeds the capacity of the total available resources. Perception, refers to the process that lead to stimulus identification (Lavie et al., 2014; Lavie & Tsal, 1994). That is, by perceiving and identifying these highly salient billboards. If in our visual field, we encounter many billboards. Then this process operates as an early selection. Contrary, if there are not many billboards (low load), the selection operates in a late stage (after some processing has already been accomplished) (Lavie, 1995; Lavie & Tsal, 1994). Lavie (1995) tested three different elements: high vs low loads, colour alone vs colour and shape and detections of features in a series of experiments. Results showed that interference from irrelevant distractors was only found in low perceptual load conditions but not in high load conditions. Lavie concluded that the ability to ignore irrelevant information is directly related to the load in the processing of relevant information. This theory has been extensively studied and has also provided evidence of individual differences in symptoms of distractibility (Forster et al., 2014; Lavie et al., 2004, 2014). In Forster and Lavie (2007), participants were asked to respond to a search perceptual task with two different loads of information. In the high load 5, non-target letters were presented whereas in the low load conditions 5 small o's as non-target were presented in a circle position Participants responded to whether the target X or Y letters were presented or not. The Cognitive Failure Questionnaire (CFQ: Broadbent, Cooper, FitzGerald & Parkes, 1982) was also used to determine the levels of distractibility for each participant, the authors were interested to find out whether there was a relationship between the level of distractibility and the scores in the perceptual task. They demonstrated that high perceptual load reduces distractor interference and that high scores on the CFQ are related to greater distractibility.

## 1.7 How are cognitive load and distractor avoidance related?

The how we prevent to looking elsewhere under the initial example (a conversation with your friend in a busy street) remain unanswered. In this section, I explain the extent to which perceptual load and cognitive load determine the efficiency of attention selection and distractor rejection. Attention selection and distractor rejection have been widely studied in the Load Theory (Konstantinou & Lavie, 2020; Lavie, 1995, 2010; Lavie et al., 2004; Lavie & De Fockert, 2005). For instance, in Lavie, Hirst, Fockert and Viding, (2004) study, five experiments were tested in a dual task paradigm with two manipulations of cognitive load. In the low condition, one digit was displayed whereas in the high condition six digits were presented. The flanker task was used in between the digit presentation and the probe displayed (Experiment 1). In the flanker task, the distractors were modified, and no neutral letters were presented (Experiment 2). Participants were asked to rehearse the digits covertly (Experiment 3). The presentation of the selective attention was modified after the memory probe (Experiment 4, 5). The results were consistent in the 5 modifications. Thus, demonstrating that high WM load impedes distractor avoidance (Experiment 1-5), and working memory load and task coordination are efficient in distractor interference (Experiment 4 -5). The next section will provide a better understanding of this cognitive mechanisms and the implications of stimulus presentation. In addition, Lavie and Fockert, (2005) used the selective attention paradigm (referred as singleton paradigm) based on Theeuwes (1992) work. In Lavie's study, they incorporated; a WM task (Experiment 1), two loads of WM: sequentially presented for low load and randomly presented for high load (Experiment 2), and one digit different for each trial in the low condition (Experiment 3). Their results demonstrated that the increment of the WM loads facilitates attentional capture to a goal-relevant stimulus and facilitates distractor avoidance even when salient properties are tested (Lavie, & Fockert, 2005). There is extensively research supporting this claim (Forster et al., 2014; Konstantinou & Lavie, 2013, 2020, 2020; Lavie et al., 2004; Pecchinenda & Petrucci, 2016). In summary, having to perform a WM task introduces a cognitive load on the observer, which seems to affect their ability to attend to targets and avoid distractors. In this thesis, I test this theory through a replication of Lavie's work (Chapter 3) and by applying this to eye movement studies of image viewing (Chapter 4 and 5). The following sections will provide an understanding of the manipulation of cognitive load by using different WM tasks.

## 1.8 How does WM work?

The term of WM refers to the ability to store and retrieve information (Baddley & Hitch, 1974; Baddley & Logie, 1999). Baddley and Hitch used this concept to refer to a system which comprises multiple components: visuospatial sketchpad, central executive and phonological loop. In the phonological loop, auditory information is firstly analysed, and remains in a short-term store (SRS), next information passes to one of the two paths: either go to a phonological output resulting in a verbal output or go to a rehearsal process. This in turn passes into the SRS as sub vocally and into the ears (if the rehearsal is overt). If the input is visual, this information passes from orthographic to phonological encoding and then to the phonological output buffer (Baddeley, 2003; Baddeley, 2001; Evans & Baddeley, 2018). The visuospatial sketchpad integrates spatial, and visual information into a mental representation which will be stored and processed (Baddeley, 2003a). This subcomponent as the previously have a limited capacity too. Estimates in visual working memory refer about 3 or 4 items to store in working memory (Baddeley, 2003a; Vogel et al., 2001).

WM is associated with neural activity in prefrontal cortex areas: frontal eye field (FEF) and the dorsolateral prefrontal cortex (dlPFC) as demonstrated in studies of macaques and humans (e.g., Bahmani, et al, 2019; Weiss, Nadj, & Bachevalier, 2016). When loading is implicated in the WM process, it has been suggested that dlPFC and parietal areas interact to boost performance (Edin, Klingberg, Johansson, McNacb, Tegner & Compte, 2009) However, it has been reported that more parietal areas, specifically the parahippocampal area (PPA) a region on the medial temporal cortex are implicated in the process of irrelevant stimuli or distractors (Yi, Woodman, Widdenrs, Marois & Chun, 2004). Yi et al (2004), used functional Magnetic Resonance Image (fMRI) to asked participants to look at a series of pictures in which a face was presented in the centre of the scene. Three conditions were tested low demand, perceptual demand and WM load; and presented with repeated and no repeated background. The authors found the BOLD signal to unrepeated scenes lower in high perceptual demand conditions than in low demand and working memory load. Thus, demonstrating a different neural process on perceptual demand and WM load. Furthermore, Zhang and Luck (2014) suggested that magnitude (low vs high loads) and resolution (change detection) affect differently to the WM process on the distractor facilitation and/or interference. In their study participants responded to a dual task paradigm (flanker task and WM). The WM was manipulated using 2 conditions of magnitudes: high load (four colours to remember) and low load (two colours to remember); and two conditions of resolution small vs big changes on the colour presentation. They demonstrated that the WM loads indeed facilitate distractor processing, whereas the WM magnitudes impede distractor processing.

Electrophysiological measures such as event related potentials (ERP) suggest the slow wave as a component to reflect the maintenance, the cognitive control processes and the effectiveness of distractor avoidance (Herrmann et al., 2009; Ortega et al., 2020). Whereas the late positive potential (LPP) is commonly studied in memory for faces (e.g, Van Dillen & Derks, 2012). Some studies have found that the increment of the fronto-central slow wave improved WM maintenance (e.g., Zickerick et al., 2020).

## 1.9 Attention Deficit/Hyperactivity Disorder

Attention Deficit/Hyperactivity Disorder (ADHD) has been associated as a consequence of a dysfunction in the prefrontal cortex affecting mainly to respond adequately to task that require sustain attention, WM and inhibition (Barkley, 1997; Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003; Sonuga-Barke, 2005). ADHD is a neurodevelopmental disorder, and the prevalence is 5.29% world-wide (American Psychiatry Association, 2013). Nearly half of the children with ADHD symptomatology continues during adulthood (Faraone, Biederman, & Mick, 2006; Pitts, Mangle & Asherson, 2015). It has been reported a range from 2.5 – 4% of adults are diagnosed with this disorder, however; there is no clear evidence of differences between gender (American Psychiatry Association, 2013; McCarhy, Wilton, Murray, Hodgkins, Asherson & Wong). The main symptomatology of ADHD is distraction, impulsivity and hyperactivity. However, the hyperactivity in which the degree and the association is presented in each person differs, therefore the DSM-5 classifies three presentations: (1) ADHD- I inattentive, (2) ADHD-H hyperactive/impulsive and, (3) ADHD-C combine (American Psychiatry Association, 2013). Although, a decrease in hyperactivity symptoms seems to be apparent during the adulthood; distractibility, poor time management, procrastination, and the make of careless mistakes seems to be more prominent in this stage (Pitts, Mangle & Asherson, 2015).

## 1.10 Cognitive impairments in ADHD

Research has found that ADHD samples with higher levels of WM impairments are more prone to have school difficulties (grade repetition, allocation in special classes, and/or extra help) in comparison to children that only have impairments in WM or diagnosed with ADHD and low levels of WM impairments (Fired, Chan, Feinberg, Pope, Woodworth, Faraone, & Biederman, 2015; Martinussen, Hayden, Hogg-Johnson, & Tannock 2005; Martinussen, & Tannock, 2006). Furthermore, in a study by Van Ewijk, et al, (2013), the authors evaluated the developmental trajectory of WM load in an ADHD sample as well as the unaffected siblings. The paradigm was designed to test the visuo spatial WM load, (high vs low). A sequence of three circles were presented in the display for the low condition whereas six circles were presented for the high condition. They found no differences between the control and the unaffected siblings' group while testing the WM load. However, the clinical group performed the worst in both conditions of the WM load. In addition, when analysing the cross-sectional sample, the outcomes suggested a development of the WM load over time. Thus, young adulthood impairments in WM load are to some extent stable in ADHD sample. Further understanding of how WM load is altered in adult samples of ADHD can lead to improving intervention for people with this clinical characteristic. Kennedy, Quinian and Brown (2016) used two measures of WM load: digits span and a story memory. In the story memory, the examiner read out loud two stories, after each; participants were asked to retell the story with as much information as they could provide. They found that the ADHD group performed worse in both tasks relative to the control group. The difference was greater when testing the story memory- WM task, relative to the numerical – WM task. The authors suggested that the story memory task is more sensitive to this specific sample relative to the numerical task.

At neural level, Kim, Liu, Glizer, Tannock, and Woltering (2014) evaluated the WM load within two conditions (high vs low) and examined the Event Related Potential (ERP) component named P3 amplitude. This neural activity change obtained from the P3 amplitude occurs about 300 ms after the stimulus presentation and it has been related in the study of the WM, specifically during the encoding. In their paradigm, participants needed to attend and shift attention between the first and the following stimulus while storing the first presented. Two different stimuli (abstract figures) were presented for the low condition whereas for the high condition three different stimuli were presented. Participants responded to the probe display whether that figure was previously presented or not. They found a reduce P3 amplitude for the ADHD group, in both WM loads in comparison to the control group. Thus, indicating and ineffective storing process in this clinical population. Furthermore, a recent study (Dobson-Patterson, O'Gorman, Chan & Shum, 2016) investigated whether performance on a neuropsychological battery contribute to differences within the symptoms of each presentation of ADHD in an adult sample. They used several neuropsychological assessments and classified them into three components: (1) Attention, (2) Memory and, (3) Executive Function (EF). Although, they did not find any differences in terms of working memory within the presentation of the disorder, they did find the ADHD-I group performed worse in the attention task component in comparison to the ADHD-C group.

In the clinical population, it has been reported effects of medication on eye movements (Bey et al., 2021; Ettinger et al., 2018). Ettinger et al., 2018 used a pro saccade task under 1 mg, 2 mg of lorazepam (a medication commonly used in anxiety disorders and ADHD) and compared with a placebo group. They showed that participants under medication had a reduction in the saccadic peak velocity. Considering these effects, studying ADHD traits within the general population seems to be a good approach to understand the nature of the disorder on eye movements.

## 1.11 Thesis aims and study design

The main aim of the present thesis is to advance our understanding of visual attention and cognitive load using complex stimuli (images and videos). Previously, I have described (1) visual attention, (2) attention deployment mechanisms, (3) the extent to which perceptual and cognitive load affect attention selection and distractor avoidance, (4) the different types of WM, and (5) ADHD. Specifically, the central research question is whether memorising different loads and presentation of information affect our visual attention to social and non-social object (with high and low salience information). Furthermore, whether ADHD-like traits affect overall eye movements.

In **Chapter 3** of this thesis a series of experiments are described in which cognitive load is manipulated between two different attentional paradigms. This chapter aimed to confirm that increases in working memory load can affect attentional deployment. In the first behavioural study, I report that higher WM load increases the effects of distractors in the classic flanker paradigm. In the second study I report a failure to replicate the previous findings, thereby questioning the manipulation of the experiment. Having confirmed the working memory load manipulation in the flanker task, **Chapter 4** aimed to understand the effect of social prioritisation, memory load, and salience information on eye movement behaviour. Furthermore, the relationship between ADHD traits within the general population and the performance of the task. In the paradigm, low and high loads of information were presented for memorizing while participants viewed complex scenes. In the image-viewing task, the stimuli have a social (a person) and non-social objects which are presented across scenes. These images have a reduction or an increment of salient information in the non-social object across the scenes. The collected data was the frequency of symptoms in ADHD. The findings from this chapter raised the question of whether these effects might be also observable when storing visuospatial information in WM. **Chapter 5** seeks to understand the effects of visuospatial WM on different presentations (sequential and simultaneous) during the image viewing task and whether ADHD traits affect this. In the task participants were asked to memorise either one or six different locations and report whether the location was previously presented or not. The findings that there is a biased towards the social area regardless of saliency raised an interest to seek an effect of instructions on the image viewing task. **Chapter 6** describes an experiment in which participants were required not to look at the two areas of interest (social and non-social). There were three different instructions 'do not look at the social area', 'do not look at the non-social area', and 'look freely'. In this chapter I also examined whether ADHD and mind wandering traits affect looking at specific areas of the image i.e., social and non-social areas. The **Supplementary Section** describes an analysis considering only the second fixations with all the image-viewing data. The research question was on whether the left-biased effect depend on content (high vs low load) and presentation (verbal vs visuospatial).

Having known that social areas have an effect of eye movement behaviour on an image viewing task, we examined the effects of social cues i.e., eyes and mouth in realistic conversation, **Chapter 7.** This chapter describes eye movement behaviour whilst watching videos of three people having a conversation. We collected data based on the frequency of symptoms in ADHD and ASD. We targeted areas of interest such as eyes and mouth. The results presented in this thesis indicate different patterns of eye movement behaviour in both subclinical populations. Results from previous chapters examining cognitive load suggest different relationships between ADHD traits and the task performance. **Chapter 8,** aimed to expand our understanding of these traits in ADHD by testing a wider sample and examining two specific components of WM, (i.e., maintenance and distractor processing).

The novelty and potential significance of this project rely on the study of how we process social and non-social stimuli while memorising different types and presentations of information. Furthermore, this thesis advance in providing evidence on how a subclinical population with evident symptoms of distractibility and inattention (i.e., ADHD) perform in such tasks.

# Chapter 2
# General Methods

This chapter describes the methodology used in the following experimental chapters. For briefness, these common methods will be described in this chapter. However, when methods differ, they will be included in the chapter. In investigating the effects of cognitive load on visual attention, Experiments 1 and 2 used the same apparatus and similar stimuli and data analysis. In investigating the effects of cognitive load on image viewing, Experiments 3 to 6 used the same apparatus, stimuli and similar data analysis. Experiments 7 and 8 examined the effects of occluding the eyes on conversation, using the same stimuli and similar apparatus and data analysis.

## 2.1 Participants

All the experiments from this thesis have approval from the Ethics Committee from the University of Essex under the following IDs: ETH1920-1682, ETH1920-0673, PMC180. JD1901.

The participants used in all the experiments were similar in most respects. Most of them were undergraduate students who were invited to participate in exchange for credits or monetary compensation. Therefore, they were aged between 18 to 30, with a similar socio-economic and educational background. Experiments 6 and 8 were slightly different in data collection. In Experiment 6, participants were recruited from the University of British Columbia, Canada. In Experiment 8, the individuals were from the general population within the UK. In this chapter, participants were aged between 18 to 59. They were all English speakers and their residence based in the UK at the moment of the study. However, in all the samples there were more females than males who contributed to the study. This thesis will not consider any effects of gender.

All participants reported having corrected or corrected-to normal vision. The eye trackers were tolerant of observers who were wearing glasses or eye makeup. If, however, these led to high rates of error during the calibration, I requested the participants to either take off their glasses or their eye makeup. If they were not feeling comfortable with this request, the participant was replaced, and they were compensated for their time with either credits or money.  Furthermore, in the behavioural studies if participants were not attending to the task and/or feeling tired during the experiment, they were also replaced and compensated for their time. The compensation depended on the length of the tasks which was equivalent to 7 GBP per hour. Before each experiment, participants provided their consent and completed questionnaires depending on the study. They were aware that they were permitted to leave at any point during the experiment. Participants were debriefed about the study before and after.

## 2.2 Stimuli

There is evidence that eye movement behaviour differs depending on the context (Foulsham & Kingstone, 2017) and whether they are in live interactions or not (Freeth et al., 2013; Ho et al., 2015). The experiments described in this thesis use a series of stimuli from static to dynamic and from simple to complex. In Chapter 3, this thesis reports replications of previous studies and uses simple visual stimuli such as digits, circles, diamonds and letters. In chapters 4, 5 and 6, this thesis uses complex stimuli: photographs of the scene containing natural images. In each scene, a social (a person embedded) and non-social object were crucial elements. The non-social object was manipulated to have high or low saliency.  The criteria for choosing these elements in the scene are described in the section 'Salience map for each non-social object within the image'. In chapter 7, this thesis uses dynamic stimuli, that is, videos. The specific considerations of these videos are also described in the next section.

This thesis uses also faces as stimuli in chapter 8. Faces attract attention in a relatively automatic way (Crouzet, 2010; Di Giorgio et al., 2012) and are complex visuospatial stimuli (Eimer, 2000). Face perception is a complex and skilled process that requires both low-level pattern recognition and also higher-order encoding (Hancock et al., 2000; Ritchie et al., 2021). These complex stimuli have been reported to be difficult to label verbally (Hancock et al., 2000; Smyth et al., 2005). For these reasons, it seems that faces are an interesting stimulus for investigating the components of working memory. Chapter 8 will describe the effects of memorising such complex stimuli over different time intervals and when a distractor is present or absent.

## 2.3 Salience map for each non-social object within the scenes

Experiments from 3 to 6 use the same stimuli. In these experiments, I used complex pictorial stimuli which included a social object and a non-social object with known bottom-up visual saliency. Previous studies on image-viewing have demonstrated how our attention is guided by top-down knowledge or guidance when we have something to search for (i.e., during visual search (Foulsham & Underwood, 2007, 2008, 2009; Underwood et al., 2006). However, top-down knowledge may be less dominant during free viewing when there is no explicit target. I examined in these experiments whether guidance to relevant objects (e.g., social stimuli) rather than salient but less relevant items would be disrupted by load during free viewing. The distinction between top-down and bottom-up guidance has been included in taxonomies of attentional guidance and has described previously in Chapter 1 (Awh et al., 2012; Benoni & Ressler, 2020; Egeth, 2018). In this thesis, I investigate these factors in the presence of load (Experiments 3, 4 and 5) and with particular instructions (Experiment 6), by examining the time course of eye movement behaviour when facing social and non-social objects with high and low saliency. Bearing that in mind a set of 64, high- resolution colour photographs were prepared as stimuli. Thirty-two pictures were used as fillers and the rest were selected following the criteria that they contained a person and an object on opposite sides of the image. The fillers were natural scenes without a social element and were presented in all the conditions. These pictures were found from different free access image databases (Braxmeier & Steinberger, 2017; Joseph, Joseph, & Frese, 2014).

The 32 experimental pictures were edited to change the salience of the non-social object. I checked the saliency of these regions using the Saliency Toolbox (Walther & Koch, 2006) via Matlab (version 9.1.0, R2016b; the Mathworks, Natick, MA) before and after a change. The parameters and implementations were obtained from http://ilab.usc.edu. The saliency of the non-social object was estimated and classified based on the first three simulated fixations. In half of the pictures, this object was classified as highly salient since it received one of the first 3 simulated fixations. The other 16 pictures were classified as containing a low saliency object which was not selected until later simulated fixations. Classifying region saliency in this way is an alternative to analysing the values in the salience map which does not require assumptions about how the map is normalised, but both methods produce similar results (see Foulsham & Underwood, 2007; Foulsham, 2019). I used PicMonkey (Habermann, 2019) to increase and/or decrease the saliency of each object within the image as well as incorporating an object to some stimuli that did not contain any. In practice, object saliency was modified by changing the colour or luminance to increase or decrease the contrast relative to the background. As described above, all images were flipped for half the participants to ensure that object type and saliency was not confounded with spatial position. The social object was a person, of which there was only one in each image. The social object was never one of the 3 most salient locations in the scene. The non-social object was chosen from one of the bigger or more prominent inanimate objects in the scene. Figure 3 depicts one image as presented in the high saliency condition. The social region of interest is the man. The non-social object is the door frame.

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*Figure 3 Representation of the stimuli: An example of a high salient no-social object.*

## 2.4 The groups conversing in the video clips

Experiments 7 and 8 use the same video clips. These video clips depicted 6 individuals (referred to as targets) having a conversation while sitting around a table. In view of each video clips, there were only 3 individuals on one side of the table.

The video clips were created from a 1 hour recording with a static video camera (with microphone) placed discretely, which is a permanent feature of the Observation Laboratory at the University of Essex. The discussion took place in a well-lit room. The video clips show 2 groups of males and 2 groups of females. They are all conversing about generic topics related to their lifestyle. In one scene the targets are wearing sunglasses and in the other they are not. Each video clip lasted 35 seconds. In these experiments, participants watched half of the video clips in which the targets were wearing sunglasses and the other not. Figure 4 shows the sunglasses condition.

*Figure 4 Representation of the stimuli: An example of a Sunglasses condition.*

## 2.5 Apparatus

Experiments from 1 to 6 used were all programmed in Matlab (Version 9.1.0, R2016b; the Mathworks, Natick, MA), using the Psychophysics Toolbox.

Two linked computers supported the eye tracking studies. Experiments from 3 to 6 used the SMI RED500 to record eye position. This is a screen-based eye tracker that samples pupil position at 500 Hz. This system monitors eye position using infra-red cameras to detect the position of both eyes.

Experiments 7 and 8 uses Eyelink 1000 (SR Research), a video-based eye tracker that samples pupil position at 1000Hz.

## 2.6 Calibration procedure

In Experiments from 3 to 6, the calibration and validation were done in a 9-point grid. Both processes were repeated several times to ensure that all recording had a mean spatial error of better than 0.8 degrees. Participants sat 60 cm away from the monitor so that the stimuli subtended approximately 43 deg by 28 deg of visual angle at 1680 x 1050 pixels. For experiment 7 and 8, the 9-point grid procedure was performed too. However, the mean spatial error was ensured of better than 0.5 degrees. Participants sat 50 cm away from the monitor so that the stimuli subtended approximately 30 deg by 17 deg of visual angle at 1024*576 pixels. The audio was played through headphones. In all the experiments using an eye tracker, a chin rest was used to restrict for any head movement.

## 2.7 ASRS Questionnaire

This thesis uses the Adult ADHD Self-Report Scale (ASRS) (Kessler et al., 2005) for Experiments from 3 to 7 and the 9. The ASRS has been investigated widely to examine traits of ADHD within a community sample (Dobrosavljevic et al., 2020; Gray et al., 2014; Kessler et al., 2005; Young et al., 2016). This questionnaire captures the current inattentive, hyperactive and combined presentation of ADHD. The ASRS is a brief self-report, standardised and well-validated tool for the assessment of ADHD in individuals above 18 years old. The ASRS consists of 18 symptoms of the DSM-IV-TR criteria for ADHD. Participants reported the frequency of the symptoms experienced over the past six months. The questionnaire is designed on a five-point Likert scale which spans 0 for never, 1 for rarely, 2 for sometimes, 3 for often, 4 for very often (Kessler et al., 2005).

## 2.8 MEWS Mind-wandering questionnaire

This thesis uses the Mind-Excessively Wandering Scale (MEWS) (Mowlem et al., 2019) for experiment 6. The MEWS consists of 15 items that reflect MW in ADHD. This scale captures typical symptoms described in the mind-wandering as an ADHD-associated impairment, such as; thoughts on the go all the time, thoughts that jump abruptly from one topic to another, and multiple lines of thoughts at the same times (Bozhilova et al., 2020; Bozhilova et al., 2018). Contrary to the conventional ADHD rating scales, this scale assesses mental phenomena (Mowlem, Agnew-Blais, et al., 2019). Participants reported the frequency of the symptoms occurring in the present. The MEWS is designed on a four-point Likert scale which spans 0 for not at all or rarely, 1 for some of the time, 2 for most of the time, and 3 for nearly all of the time (Mowlem, Skirrow, et al., 2019).

## 2.9 AQ10 Questionnaire

This thesis also uses the adult AQ-10, which is an abbreviated version of the Autism spectrum Quotient (AQ) (Allison et al., 2012). The AQ-10 consist of 10 items that classify individuals as having or not ASD. The 10 items capture the ability or difficulty on 5 different areas: (1) attention to detail, (2) attention switching, (3) communication, (4) imagination, and (5) social (Ashwood et al., 2016, p. 1; Booth et al., 2013; Wigham et al., 2019). The AQ-10 scores only one point for each question considering definitely agree, slightly agree, slightly disagree and definitely disagree (Allison et al., 2012).

## 2.10 Data Analysis

The manual responses measure i.e., accuracy and reaction time from experiments 1 to 5 and 9 were calculated from the keyboard responses logged in the data file. These responses were averaged per condition and per participant depending on the research question of the experiment. The cut-off for the reaction times and accuracy differ depending the research question of each experiment. The rule of thumb was that reaction times over 100ms and under 3000 ms were included on the analysis. For accuracy I only included responses which were above chance.

The ASRS and MEWS were completed by the participants on paper. These scores were computed in a different file and matched with their corresponding participant number for all the experiments.

## 2.11 Data Analysis defining Areas of Interest (AOI)

Both eye tracking system computed sample data indicating the location in x and y coordinates of each fixation per participant and per condition.

From the SMI eye tracker, the IDF event detector file was converter into a text file. The output contains information related to different events such as fixations, saccades and blinks. For the purposes of this thesis, I only used the fixation data for all the participants. In each file, the fixations describe the chronological order, the trial, the duration, the average pupil size, the location and dispersion in x and y. Due to theoretical relevance for the chapters, the trial, chronological order, duration and location were only included.

Regarding the AOIs for images in experiments 3,4,5 and 6, I delineated the social and non-social area considering the minimal and maximum x and y for each element. This file was integrated into each of the output from the participants and examined whether the fixations were on the AOI for social or non-social object or elsewhere. In all the cases, means were compared between conditions using analysis of variance (ANOVA). The alpha level of 0.5 was set for all the analyses.

In experiment 7 and 8, a static AOI was drawn around each of the 3 targets using Data Viewer's inbuilt function. From these outputs, I obtained information such as: the trial, the condition, the participant number, the fixations location and duration and the fixations location and duration in the AOI. Furthermore, the means were compared within conditions and between groups using analyses of variance (ANOVA).

## 2.12 Justification of sample sizes

In chapter 3, I aimed for a sample size greater than that in the original studies (Lavie, 2004; 2005). These studies have 11 (Experiment 1; Lavie, 2004) and 8 participants (Experiment 1; Lavie, 2005). I also carried out a power analysis by simulation using Superpower (Lakens & Caldwell, 2021). Considering a strong within-subjects correlation, a sample of 5 participants is enough to detect the original effect of compatibility. From chapter 4 to 8, all the sample sizes were set a prior and pre-registered.

# Chapter 3
# Evidence for The Effect of Working Memory Load in the Facilitation of Distractor Rejection in a Flanker Task but Not in the Singleton

**Abstract**

Load Theory of selective attention argues that high cognitive load impedes distractor avoidance (see, Lavie et al 2005). In this chapter, I report two experiments investigating the effect of WM load on selective attention. Experiment 1 showed that high WM load increases the effects of distractors in a flanker task. However, in Experiment 2, the singleton paradigm, this effect was not observable. In this chapter, I discuss the failures of not have found such effects. Considering these results, I then investigated the employment of cognitive load in a novel context in Chapter 4 and 5.

## 3.1 Introduction

The main aim of this chapter was to confirm that increases in working memory load can affect attentional selection, as has been reported previously (Lavie et al, 2004). It was important to verify the effectiveness of our manipulation of WM before employing it in a novel context in Experiment 3, 4 and 5.

### Working memory load and visual attention

The biased competition model provides evidence that working memory and visual attention are closely related. When one's task is to attend to a specific object from a stimulus (i.e., scene), we activate mental representations or a target template (e.g., Bundesen, 1990; Duncan & Humphreys, 1989) of the to-be-attended object (recruiting working memory) for instance colour, texture, shape, etc. Once the display appears, selection is biased towards the target object as it matches this target template (Desimone & Duncan, 1995). The related question of how working memory is related to the ability to exclude and reject distractors is currently receiving substantial empirical scrutiny but remains to be fully understood. A number of previous studies have investigated how visual attention and working memory (WM) interact with each other in the context of distractor interference (Cashdollar et al., 2013; Downing, 2000; Konstantinou & Lavie, 2020; Lavie, 2010; Olivers et al., 2006). The following everyday life example serves to illustrate how working memory and distractor interference might be related. When shopping in the supermarket for salad leaves you are likely to retrieve information from long-term memory about the appearance of the target and hold this in your working memory, creating an active representation or target template. This representation serves to specify your goal during the shopping expedition and should serve to guide your attention towards the sought-after product. However, the supermarket is filled with competing products that you do not intend to purchase. In order to choose the target product, it is important to reject and avoid these distractors. Avoiding interference from irrelevant distractors can be especially difficult when products are physically salient (recall the bright red packaging of the Doritos pack). It seems likely that under such a scenario increasing our cognitive load by trying to remember the phone number for the taxi we need to call to return home, will increase the interference from these highly salient distractor products, and prolong our shopping trip. The load theory of attention and cognitive control, provides one concrete theoretical framework that captures the memory-related interference effects (Forster et al., 2014; Konstantinou & Lavie, 2020; Lavie, 2005, 2010; Lavie et al., 2004). Load theory proposes that an increase in the perceptual difficulty of a primary task (perceptual load) serves to reduce the perceptual processing resources available to process task irrelevant distractors thereby reducing the extent to which these distractors interfere (Konstantinou & Lavie, 2020; Lavie et al., 2004). In addition, disrupting the availability of WM resources to maintain our goals, serves to increase interference from task irrelevant distractors (Cashdollar et al., 2013; Forster et al., 2014; Lavie, 2010; Lavie et al., 2004). Similarly, the executive attention theory provides evidence that working memory capacity varies between subjects, and that different cognitive tasks make differential demands on this available capacity, by drawing on executive-control processes involved in storing and retrieving access to stimulus in face of conflict or distractors (Engle, 2002; Poole & Kane, 2009). This theory is suggestive that greater WM capacity means better ability to filter out any irrelevant information or distractor.

Behavioural experiments are consistent with WM being crucial in avoiding distraction from irrelevant stimuli. When participants are required to remember a set of alphanumeric stimuli whilst selecting a target, performance is slowed when the irrelevant distractor is incompatible with the target (e.g., x when the target was z) and this interference increases under high WM load (Forster et al., 2014; Lavie, 2005; Lavie et al., 2004). Interference from a physically salient distractor has also been shown to increase under a high WM load (Lavie & De Fockert, 2005). These results demonstrate that the ability to reject distractors is impaired when WM is taxed, suggesting that WM plays an important role in attentional selection.

## 3.2 Overview of experiments

In our first experiment, we attempted a near-direct replication of the increased distractor interference for high working memory loads of described by Lavie et al. Participants completed a verbal working memory task with a flanker task. In the flanker task, we did not show the target letters in the six different locations as in the original paper only in the centre. We found increased distractor rejection in the low load condition. Experiment 2 attempted to modulate the interference caused by a salient but irrelevant singleton in a search task (Lavie, et al, 2005; Theeuwes, 2005). We failed to replicate the results described in the original paper (Lavie, et al,2005). Whilst the results showed a numerical trend such that there was a numerically larger effect under high than low load conditions, this difference was not statistically reliable. Thus, we have no evidence to support that proposal that a high verbal working memory load serves to increase the interference from a salient distractor.

## 3.3 Experiment 1

In Experiment 1 of Lavie et al (2004), the authors asked participants to memorise a set of six letters for the high-load condition and a single letter for the low-load condition. Next participants needed to respond to a target letter by pressing of two different keys, whilst simultaneously ignoring a distractor letter presented above or below the target letter. The target could be located in any of the six different positions from the high-load memory condition. The distractor had three different identities: (1) compatible with the target (e.g., the same letter), (2) incompatible with the target (a different but response relevant letter), (3) and neutral (a letter not associated with any response). Results from this experiment showed that participants were slower in the incompatible condition than the compatible as expected from the flanker task. Furthermore, the reaction times were increased in the high-load condition than in the low-load. Of greatest importance the compatibility effect was increased under conditions of a high working memory load. We attempted a direct replication of the memory and flanker task.

## 3.4 Methods

## 3.5 Participants

Twenty-one participants (ages 19 – 43, *M* = 26 *(SD = 6.16)* years, 18 females) were part of this study.

## 3.6 Stimuli

We replicated Experiment 1 from Lavie et al (2004). Figure 5 shows a schematic representation of the paradigm. Each trial started with a fixation dot displayed for 500 ms, followed by the WM load display. For the one-digit presentation (low-load) this remained on the screen for 500 ms and for the six-digits presentation (high-load) 2000 ms. For both loads the digits were chosen randomly from 1 to 9, with no repetition and in a random order. A mask display was presented for 750 ms for the one-digit presentation and 2500 ms for the six digits presentation, followed by a fixation point presented for 500 ms. The presentation duration of the low and high sets were chosen as in Lavie et al (2004) to ensure that participants have sufficient time to read all the digits. The target letter in the selective attention task was either a "z" or an "x", presented in lowercase and located always in the centre of the screen. A distractor letter (the flanker) was presented above or below the target and was either compatible (i.e., x-x), incompatible (i.e., x-z) or neutral (i.e., the letter n). For the selective attention task, participants were required to press z if the target letter on the display was a "z", or x if the target letter on the display was a "x". After the response to the selective attention task, participants were required to respond whether the probe digit was presented previously by pressing the right or left arrow key on the keyboard. Participants were instructed to respond as fast as possible in both tasks. All the combinations (target identity, distractor identity and distractor position) were counterbalanced and presented in a random order. According to these specifications, ninety displays were created for each condition of working memory load. Both conditions were blocked. There were two experimental blocks, preceded by two blocks of practice with 5 trials each. The experiment took a total of approximately 40 minutes.

**Design**: A two factors design was employed with reaction times and accuracy responses from memory (high - low), and compatibility (congruent - incongruent).

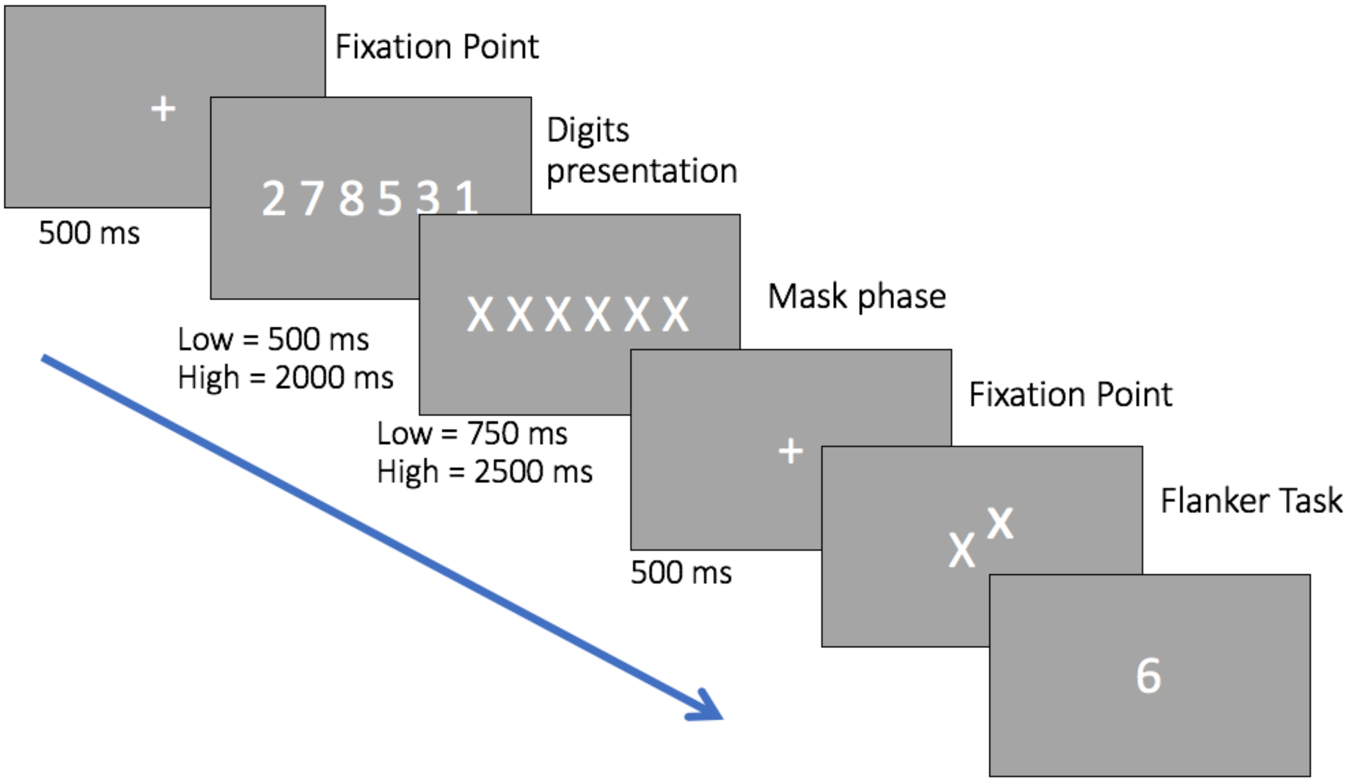


*Figure 5 Schematic representation of the stimuli and procedure of Experiment 1.*

## 3.7 Data analysis and Results

Only participants who scored above chance on both tasks were included in the analysis. This resulted in five exclusions. From the remaining sixteen participants' data, trials on which the participants were correct on the memory task and with RT's over 100ms and under 2000 ms were included on the analysis.

| WM | Low | | High | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Compatible | 946 | 126 | 960 | 106 |
| Incompatible | 992 | 136 | 1083 | 122 |
| Neutral | 994 | 162 | 1061 | 167 |

*Table 1 Mean Correct Reaction Times (in milliseconds) on the flanker task as a function of the WM and distractor compatibility.*

Table 1 presents the mean and standard deviation reaction time on the flanker task as a function of WM load and distractor compatibility. A two-way within-subject ANOVAs on flanker RT as a function of working memory load (low, high) and distractor compatibility (compatible, incompatible) revealed a significant main effect for distractor compatibility F (1, 15) = 18.484, p = .001 $\eta^2 = .552$, indicating that responses in the compatible condition are significantly faster than the incompatible condition. There was no significant main effect of memory load on reaction times F (1, 15) = 2.195, p = .159 $\eta^2 = .128$. However, there was a significant interaction between working memory load and distractor compatibility F (1, 15) =7.897, p = .013 $\eta^2 = .345$. Follow-up, paired comparisons revealed that distractor compatibility effects (compatible vs. incompatible) were significant in high-load trials, t (15) =-5.405, p < 0.001, but reduced such that they failed to reach significance in low-load trials, t(15)=-1.852, p = 0.08.

A paired-samples t-test was conducted to compare the accuracy in the congruent conditions: for low-load 95.25 % (SD = 6.96) and high-load 90.72 % (SD = 10.84). There was not a significant difference t(15)=2.021, p= 0.062. The same analysis was conducted to compare the accuracy in the incongruent conditions: for low-load 96.08 % (SD= 5.09) and high-load 91.13 % (SD= 8.01). There was a significant difference t(15)= 2.447, p< 0.027.

In a last analysis, as in Lavie et al (2004), we calculated the magnitude of the interference effect (difference between incompatible and neutral condition) and the magnitude of the facilitation effect (difference between compatible and neutral condition) for each participant. These two variables were then entered into a 2 (WM: high and low) x 2 (component: interference and facilitation) within subject ANOVA. The results revealed a significant effect of component F (1, 15) =18.484, p > 0.001, $\eta^2 = 0.552$, no effect of WM load (F<1), and an interaction of component and WM, $F(1, 15) = 7.897$, $p = 0.013$, $\eta^2 = 0.345$. The interaction is consistent with memory load increasing the interference from an incompatible distractor to a greater extent than the facilitation from a compatible distractor.

## 3.8 Experiment 2

Experiment 2 applied the same WM manipulation to the typical singleton attention paradigm (Theeuwes, 2018; Theeuwes et al., 2003) to examine whether increasing cognitive load would increase the interference from a salient singleton. In the original paper of Lavie et al (2005) experiment 1, the authors asked participants to memorise six digits or none. In the search task, participants needed to search for a circle among diamonds and report the orientation of the line within it (either vertical or horizontal) by pressing a keyboard response while ignoring a singleton that was present on half of the trials. Results from this experiment showed that responses from the singleton-present condition were slower than the singleton-absent. Furthermore, the results showed an interaction between the singleton and the memory task, indicating an increment in the singleton effect when memorising information than when not. We attempted a replication of the task by adding two different loads of information one digit as low-load and six digits as high-load. We would expect to see a greater singleton effect for the high load comparing to the low load

## 3.9 Methods

## 3.10 Participants

Twenty participants (ages 18 – 33, *M = 24.15 (SD = 4.31)* years, 15 females) were part of this study.

## 3.11 Stimuli and apparatus

Apparatus was the same as Experiment 1, Figure 6 illustrates the procedure underlying Experiment 2. The memory task was the same as Experiment 1. In the attention task, participants were required to search for a circle among diamonds and make a fast response to the orientation of a line inside the circle by pressing the 'z' if the line was horizontal or 'x' if the line was vertical on the keyboard. The attention task consisted of a circle of 6 shapes equally spaced. The circle radius was 3.40 deg from fixation to the centre of each shape. The target shape was a circle of a radius of 0.7 deg. A white line 0.5 deg long was positioned in the centre of each shape. These lines were either vertical or horizontal. The line direction was randomly assigned. The singleton was always colour red whereas the other stimuli were green. The background was black. The lines inside the shapes were colour white. The various combinations of target line tilt, target position, singleton presence and position occurred equally often in each block.

There was a distractor (irrelevant colour singleton) present in half of the trials. Each participant performed two blocks of memory (low and high load) of 50 trials each, preceded by two practice blocks of 5 trials each. The experiment took a total of approximately 50 minutes. Participants were instructed to indicate as accurately as possible whether the memory probe was present in the memory set as the first trial by pressing left arrow key to absent or the right arrow key to present.

**Design**: A two-factors design was employed with reaction times and accuracy responses from memory (high - low), and singleton (present - absent).

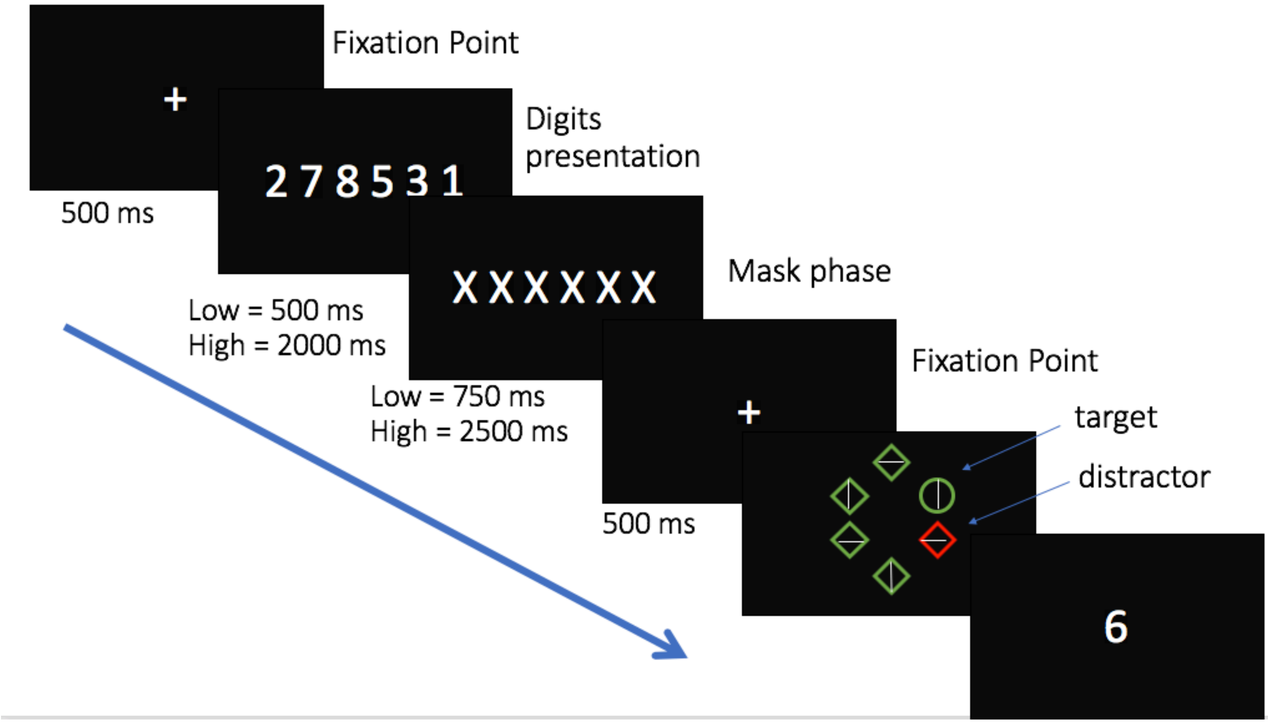


*Figure 6 Schematic representation of the stimuli and procedure of Experiment 2.*

## 3.12 Results

Only participants who scored above chance on both tasks were included in the analysis. This resulted in one exclusion. From the remaining participants' data, trials on which the participants were correct on the memory task and with RT's over 100ms and under 3000 ms were included on the analysis. A paired-samples t-test was conducted to compare the accuracy in the memory conditions: for low-load 83.65 % (SD = 7.11) and high-load 74.25 % (SD = 10.62). There was not a significant difference $t(19)=-3.539$ $p= 0.002$.

| WM | Low | | High | |
|---|---|---|---|---|
| | Mean | SD | Mean | SD |
| Present | 1.23 | 0.31 | 1.27 | 0.31 |
| Absent | 1.16 | 0.23 | 1.18 | 0.23 |

*Table 2 Mean Correct Times (in milliseconds) on the attention task as a function of the WM and singleton absent or present.*

Table 2 represents the mean and standard deviation on the attention task as a function of the WM and singleton absent or present. A two-way within-subject ANOVAs on the attention task RT as a function of working memory load (low, high) and singleton (absent, present) revealed a significant main effect for singleton presence $F(1, 18) = 13.904$, $p = .002$ $\eta^2 = .436$, indicating that the absence of singleton facilitates responses compared to the presence of singleton condition. There was no main effect of memory load on reaction times $F(1, 18) = .384$, $p = .543$ $\eta^2 = .021$. There was no interaction between working memory load and singleton presence $F(1, 18) =.423$, $p = .523$ $\eta^2 = .023$.

## 3.13 General Discussion

The current chapter successfully replicated experiment 1 from Lavie et al (2004) but failed to replicate the main finding in singleton capture from Lavie et al (2005). It might be worth noting that in Experiment 2 there is a trend in the expected direction. First, in replication of Lavie et al (2004), Experiment 1 confirms that the manipulation of memory load is adequate to disrupt performance in a response competition task which is consistent with the Load Theory of Selective Attention (Lavie et al, 2004). However, we had smaller distractor compatibility effects (compatible vs. incompatible) than those reported by Lavie et al (2004). It is important to note, that our RT were larger (in 100 ms) than those typical effects reported previously (Konstantinou & Lavie, 2020; Lavie et al., 2004).While previous studies have more trials in the practice phase than Experiments 1, we do not rule out the possibility that these lack of trials are the cause of these larger effects in RT. Although these effects can accommodate well the load theory in which higher loads of WM provides goal-directed control of visual attention, it enables interference by distractors (Konstantinou & Lavie, 2020; Lavie, 2010; Lavie et al., 2004).

Second, in replication of Lavie et al (2005), Experiment 2 showed a strikingly different pattern. There, memory-load had no interaction with singleton capture. In considering the effects from Experiment 2, it is important to consider the RTs are quite larger that reported in previous literature (Lavie & De Fockert, 2005; Theeuwes, 1991, 2018). The attentional selection task (in Experiment 2) has RT above 1000 ms which are long for the traditional 'pop-out search task' (see Theeuwes, 1991). The magnitude effects are larger (70 – 90 ms) than previously reported (Lavie & De Fockert, 2005). It is plausible that all participants are experiencing some difficulties with the tasks, as having two tasks may provide some cost. We do not rule out the possibility that more practice trials might provide a reduction in the RTs since in Experiment 2, participants only practice for 10 trials.

Furthermore, the difficulty of the memory task is also an important factor to consider. The critical question in these studies, is whether memory load adequately taxes cognitive load and whether the high load condition is sufficiently different from the low load condition in making a differential draw on cognitive load. In Experiment 1, working memory load interacted with congruency in a flanker task. However, in Experiment 2, the memory load manipulation had little effect on the attentional paradigm in the presence of a singleton. In Lavie et al (2005) study the manipulations of memory loads where different from our Experiment 2. In their study, the load conditions vary among the three experiments. In the first experiment, they compared no-load vs high load (memorising 6 digits). In the second experiment, the same number of digits (4) were presented in both loads: low-load (sequential order) and high-load (random order). In the third experiment, high-load as experiment 2 and low-load one digit different from the others. These manipulations and other studies (for example in Burnham et al., 2014) that have examined cognitive load and singleton capture tended to used load tasks that require participants to either rehearse the times or to retain the order additionally these compared against a null no task baseline rather than a low load. In Experiment 2, there is no order requirement and no comparison either against a null baseline task. Then it is plausible that since Experiment 2 did not require ordered recall the task primarily loads phonological memory, consequently, does not change the singleton effect. If that is the case, these results are consistent with Burnham et al., (2014). The authors did not report an effect of cognitive load on the phonological loop.

In conclusion, this chapter in Experiment 1 confirms that increases in working memory load can affect the attentional selection and has effectively verified the manipulation of cognitive load to be used in a novel context. Surprisingly, however, the same load task does affect the flanker task, but not the singleton task. These effects (in the singleton task) suggest that this particular implementation of load task affects later stages of response selection rather than earlier stages of distractor exclusion at a perceptual level.

# Chapter 4
# The effects of verbal WM on an image-viewing task and ADHD- traits

**Abstract**

In this chapter, I used the same manipulation of WM load from Experiment 1 to probe attention during the viewing of complex scenes while also investigating individual differences in ADHD traits. In here, I measured the degree to which fixations targeted each of two crucial objects: (1) a social object (a person in the scene) and (2) a non-social object of higher or lower physical salience. We compared the extent to which increasing WM load would change the pattern of viewing of the physically salient and socially salient objects. The results showed that the social object was fixated to a greater degree than the other object (regardless of physical saliency). Increased saliency led to increased fixations on the non-social object but did not change fixations on the social object. Increased levels of ADHD-like traits had a small effect in only one condition. Importantly, working memory load did not affect number of fixations on the social object. Such findings suggest rather surprisingly that attending to social areas in complex stimuli is not dependent on the availability of voluntary top-down resources.

## 4.1 Introduction

Recently, there has been evidence that eye movements reflect working memory relevance as a function of scene viewing. For instance, it has been suggested that memorising verbal or visual information affects eye movement behaviour. This research suggests that fewer fixations are made when participants are required to hold information in memory, compared to when they are unencumbered (Cronin et al., 2020). However, it remains to be seen whether guidance to specific items (i.e., the decision of "what" to look at) is affected by working memory load in complex images. The primary aim of the current study was to investigate if loading working memory would interfere with the default preference to look at specific areas in scenes.

### *4.1.2 What determines where people look in scenes?*

The physical properties of stimuli can be an important determinant of eye-movements. In particular previous research has identified salience from feature contrast (the extent to which an element differs from its surroundings in a single physical feature) as a major determinant of interference (Itti & Koch, 2000; Theeuwes, 2010; Underwood et al., 2006; van Zoest et al., 2004; van Zoest & Donk, 2005). In research using simple displays, the presence of a singleton distractor (e.g. red distractor amongst green distractors) can cause significant interference with the ability to select and locate a simple target (square target in circular distractors) (Theeuwes et al., 2003; Theeuwes & Failing, 2020). Such singleton capture can impact on patterns of eye movements, in particular early fixations (van Zoest & Donk, 2005), and fast eye-movements made within a few hundred milliseconds of the presentation of a visual display (Donk & van Zoest, 2008). Singletons in this task are also more distracting when the observer's working memory is loaded with an additional task (Lavie & De Fockert, 2005). Other research has investigated the influence of stimulus saliency in more complex scenes by comparing the pattern of fixations (in terms of time and location) to those predicted by a saliency map model (Anderson et al., 2015; Foulsham & Underwood, 2007, 2008, 2009; Underwood et al., 2006). For instance, the Itti and Koch (2000) saliency map model suggests that each location in a scene is assigned a salience value, that determines the likelihood that it will be selected and fixated first. Across a set of basic feature dimensions (e.g., intensity, colour and orientation) each object is compared with the local surroundings. Objects are more salient if they are locally distinctive, differing from the surround. The dimension specific salience values are summed together in a salience map that loses information about the source of the contributing signals e.g., is dimension independent. Although it has been suggested that early fixations are made to salient regions (Anderson et al., 2015), the saliency effect is strongly modulated by task instructions and demands (Foulsham & Underwood, 2007, 2008, 2009; Underwood et al., 2006).

Other studies have reported a more pervasive influence of socially relevant stimuli (a person within the picture) on eye movements (End & Gamer, 2019; Flechsenhar et al., 2018; Foulsham et al., 2010). In contrast to physical salience, social salience appears to bias both earlier and later fixations (End & Gamer, 2019; Flechsenhar et al., 2018). For example, End and Gamer (2019) asked participants to freely view naturalistic scenes (or to specifically direct fixations to the socially relevant areas). In their images four areas of interest were considered: head and body of the person embedded in the scene, high salient areas, and low salient areas based on a saliency map model. They found more fixations to the head in both task instructions in comparison to the other areas. These findings are consistent with participants being strongly biased towards social information, regardless of physical saliency, and with seemingly little effect of instructions. (Laidlaw et al., 2012) asked participants to avoid looking at specific areas of the face (eyes or mouth) or to look freely to inverted and upright faces. In Experiment 1 with upright faces, participants made more errors (looking to the eyes when told not to look at the eyes) compared to when told not to look at the mouth. In Experiment 2 with inverted faces participants made errors equally in both conditions. The interesting aspect of the "do not look" conditions is that participants were not able to control looking at the eyes but looking at the mouth seems easier for them (Experiment 1). This difference was not apparent when the faces were inverted, indicating that it was not due to simple bottom-up aspects of the eyes but rather their meaning within the face. The aim of the current study was to further investigate the social bias in scene viewing and to test whether the bias to view social objects is dependent on top-down control resources.

### *4.1.3 Individual differences on image viewing task*

We also consider whether individual differences might affect the balance between load, top-down and bottom-up visual attention. There is relatively little known about the relationship between individual differences and eye movement behaviour in image-viewing. Recently, Hayes and Henderson, (2017, 2018) have investigated this relationship by analysing scan patterns during the viewing of indoor and outdoor scenes. In their first study, they investigated individual differences in eye movement behaviour related to intelligence, working memory capacity and speed of processing. After an image-viewing task, participants were asked to complete a series of cognitive measures (as secondary task). Specifically, for working memory, the authors used two different span tasks: arithmetic and reading. In the arithmetic span, participants with the highest scores fixated more on the top left-hand side, on the centre and on the bottom right-hand side of the image than the rest of the image. The participants with the lowest scores fixated more on the left-hand side areas than other areas. In the reading span task, participants with higher scores fixated more on the top left areas than other areas. Participants with lower scores fixated more on the bottom right areas than other areas (Hayes & Henderson, 2017). This evidence shows that differences in cognitive task performance might correlate with overall eye movement behaviour. Hayes & Henderson, (2018) also investigated individual differences in clinical traits: Attention Deficit Hyperactivity Disorder (ADHD), Autism Spectrum Disorder (ASD) and Dyslexia symptoms, assessed by self-report questionnaires. ADHD behaviour was characterised by a bias towards the upper area of the scene with shorter state transition. ASD behaviour was characterised by a bias to move and/or remain within the upper area. Interestingly, dyslexia and ADHD had a similar pattern on prediction weights, indicating an overlap in behaviour. Given these findings, it appears that scanning behaviour may provide a measure of clinical and cognitive individual differences. However, it is not clear yet whether these individual differences affect looks at particular salient or social objects.

We focus on individual differences related to ADHD since this disorder has been frequently linked to working memory and attention. ADHD is a heterogenous disorder with an overall population prevalence of 5.29% world-wide (American Psychiatric Association, 2013). Whilst primarily a disorder affecting children, it can persist into adulthood, albeit with reduced prevalence 2.5 – 4% of adults (American Psychiatric Association, 2013; Faraone, 2000). ADHD is associated with deficits in visual attention, WM, and inhibition (Barkley, 1997; Crosbie et al., 2013; Faraone, 2000; Nigg, 2001; Sergeant et al., 2003). In the last decade, extensive research has been devoted to study clinical-like behaviour within community samples as a form of traits (i.e., Crosbie et al., 2013) or with unaffected siblings (Gau & Shang, 2010; van Ewijk et al., 2014). Studies have demonstrated that people with ADHD performed worse than control patients during a WM task (Gau & Shang, 2010; Kasper et al., 2012; van Ewijk et al., 2014). Yet, there are inconsistencies in ADHD-like behaviour in the presence of working memory load. For instance, Gau and Shang, (2010) reported the unaffected siblings' behaviour to be similar to the clinical group whereas van Ewijk et al., (2014) reported the unaffected siblings' behaviour to be similar to their control group . Research has also shown that people with high traits of ADHD have an abnormal rate of microsaccades in comparison to those with low traits of ADHD during the performance of a sustained fixation task (Panagiotidi, Overton & Stafford, 2017). Furthermore, research has reported that boys with ADHD made slower and less accurate saccades than their typical counterparts in a search task (Van der Stigchel et al, 2007). In addition, children with ADHD are reported to have poor fixation capability in comparison to a typical comparison group when they needed to look at a fixation point, and when looking at a fixation point while avoiding a distractor (Caldani et al, 2019). Of particular relevance to the current work, participants with clinically diagnosed ADHD show increased interference from an irrelevant distractor in comparison to healthy controls (Forster et al, 2014). Together these findings indicate impairments in both WM mechanisms and distractor rejection in an ADHD group as well as some evidence of atypical eye movements on ADHD-like behaviour.

The main aim of the present study was to determine the role of top-down control processes related to working memory in establishing and maintaining this social viewing pattern. To this end we investigated how asking participants maintaining a high or low memory load would impact on the viewing patterns. According to the load theory of selective attention, (Cashdollar et al., 2013; Forster et al., 2014; Lavie, 2010; Lavie et al., 2004), high working memory load should disrupt top-down cognitive control. If the bias towards social stimuli arises as a consequence of top-down goals that bias participants towards social stimuli in the absence of competing goals, we should expect the bias towards social stimuli to be reduced under conditions of high working memory load. This might especially be the case in the face of strong bottom-up physically salient objects in the scene. In contrast if the bias towards socially salient stimuli arises in a way independent of top-down mechanisms related to working memory it should be unimpeded (End & Gamer, 2019; Flechsenhar et al., 2018). Furthermore, we aimed at studying whether severity of sub-clinical symptoms of ADHD might affect eye movements whilst free viewing the scenes. If the tendency to select scene objects depends on top-down control processes linked to working memory and these processes are impaired in those displaying ADHD behaviours (Crosbie et al., 2013; Forster et al., 2014; Gau & Shang, 2010; Kasper et al., 2012; van Ewijk et al., 2014), increased ADHD traits may serve to reduce the bias towards socially relevant objects.

We examined how the pattern of eye-movements that participants make whilst free-viewing complex images would be affected by the same memory load manipulation. We asked participants to view the images to get a measure of natural-looking behaviour. The scene images contained multiple objects, one of which was a critical “social object”. In addition, in each scene a non-social object was identified, and two versions of the scene were created. In the low physical salience condition the object was unchanged, whereas in the high physical salience version the object was edited in a way to increase its physical salience. Saliency was estimated using Itti & Koch's (2000) model. We expected to find a preference for the socially salient object that is present even in the face of the presence of physically salient object, as has been demonstrated previously (Birmingham et al., 2009; End & Gamer, 2019).

## 4.2 Method

## 4.3 Participants

We tested 60 participants (ages 18 – 35, *M* = 24.28 years, 41 females). After discarding data from 10 participants who were not accurate in the calibration (above 0.8 deg, a threshold set a priori), the final sample consisted of 50.

## 4.4 Apparatus and Stimuli

Before the experiment, participants were required to complete the Adult ADHD Self-Report Scale (ASRS; Kessler at al., 2005).

Figure 7 Illustrates the procedure for each trial in Experiment 2. The memory task was the same as in Experiment 1. In the image-viewing task, the picture was shown for 5000 ms. Participants were instructed to look freely at the picture. After the scene, the memory probe display was presented. Participants were required to respond whether the probe digit was presented previously by pressing the right or left arrow key on the keyboard.

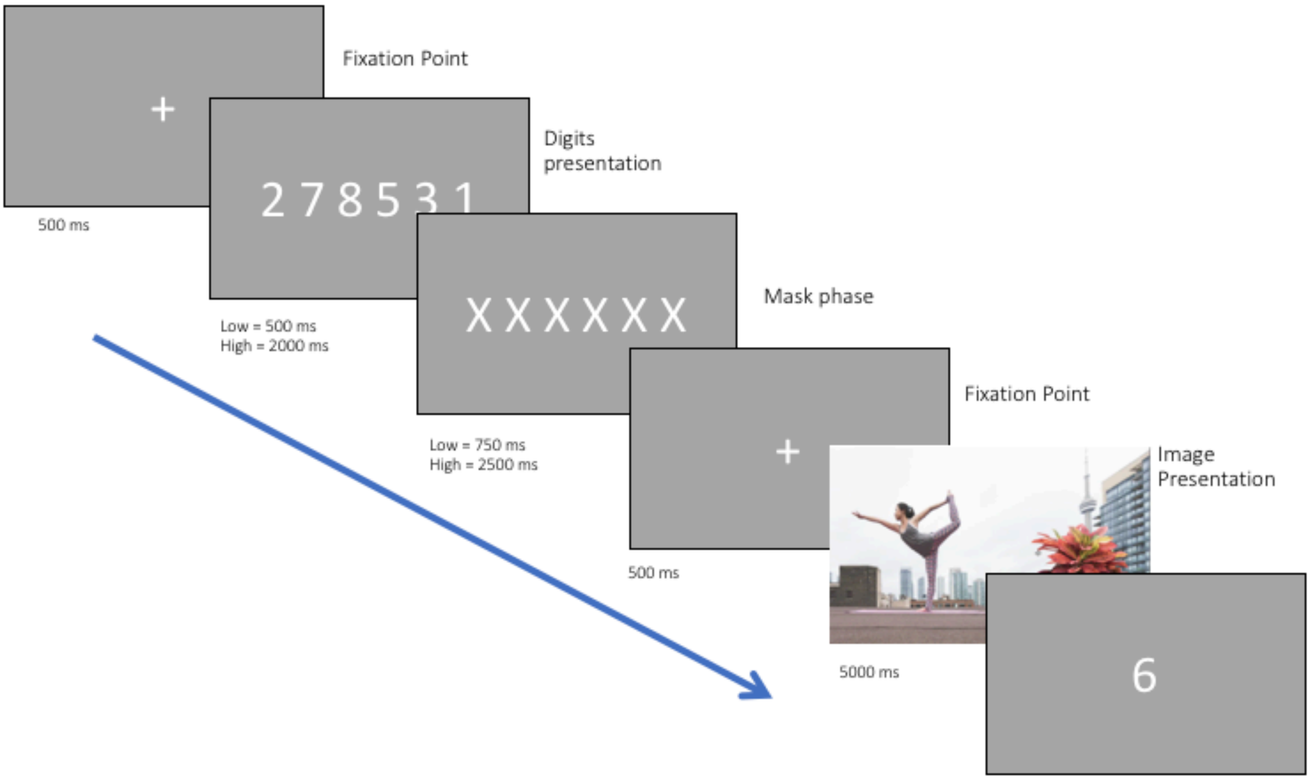


*Figure 7 Schematic representation of the stimuli and procedure of Experiment 2. This condition is high WM and a high salient non-social object. Digits are shown larger than in the actual experiment.*

The experiment consisted of two blocks: one-digit (low load) and six digits (high load) presentation. Each block consisted of 32 trials. Half of the participants started with the one-digit presentation and the other half with the six-digit presentation. Experimental images were counterbalanced across participants such that each particular scene appeared in all load and saliency conditions, and each was mirror reversed for half the participants to control for any biases to the left or right of the image. There was a total of eight different versions formed by a combination of the following factors: flipped image (original, flipped) memory probe (present or absent), and object saliency (high or low). Participants were assigned randomly to one of the eight different versions. Only the factors of distractor saliency and memory load were of theoretical interest. The experiment took a total of approximately 25 minutes.

**Design**: Two different designs were employed. The first, a two-factor design on the probability of fixating on the non-social object with memory (high and low), and non-social object saliency (high and low). The second, a two-factor design on the probability of fixating on the social object with memory (high and low), and non-social object saliency (high and low).

## 4.5 Data analysis

Participants who scored below 50% on the memory probe were excluded from the analysis. Fixations were removed if their duration was below 100 ms. We also excluded trials where the starting fixation was not recorded on the centre and those with incorrect memory responses. Following these criteria, we analysed data from 45 participants.

## 4.6 Results

We examined the effect of working memory load on the image viewing task. We first examined the effect of working memory load on fixations to both ROIs (social and non-social). Then, we examined the effect of working memory load and saliency on fixations to the non-social ROI. Finally, we investigated whether symptoms of ADHD are related to eye movement behaviour as well as accuracy and reaction time in the memory task. Our dependent variables were (1) accuracy in the WM task, (2) reaction time in the WM task, (3) total number of fixations, (4) average fixation duration per ROI, (5) overall probability of fixations on the non-social object, (6) overall probability of fixations on the social object, (7) the ADHD trait scores from the ASRS.

## 4.7 Behavioural data

Accuracy in the WM task: Accuracy in the memory task was lower in the high-load condition (M= 88.52%, SD = 12.66), and slightly higher in the low-load condition (M= 94.50, SD= 9.09). A paired sample t- test was conducted to compare the accuracy to the memory probe under high and low loads, $t(44) = -3.893$, $p < .001$. Furthermore, a paired sample t- test was conducted to compare the reaction time to the memory probe under high and low loads. The reaction time in high-load trials (M = 1,447 ms, SD = 1064) and low-load trials (M = 1,149 ms, SD = 642) was only marginally different, although this difference was consistent with the high load condition being more difficult; $t(44) = -1.840$, $p = .072$.

## 4.8 General eye movement statistics

Table 3 shows general eye movement statistics across trials and across participants as a function of working memory load and saliency to the non-social object.

We analysed the number of fixations to get an overall idea of viewing behaviour as well as the mean duration of fixations.

| WM | High load | | Low load | |
|---|---|---|---|---|
| **Saliency of non-social object** | HS | **LS** | **HS** | **LS** |
| N fixations/trial | 20.29 | 20.24 | 19.71 | 20.18 |
| Average fixation duration in ms | 207.09 | 207.49 | 214.23 | 210.29 |

*Table 3 Represents the total number and average duration of fixations as a function of condition and trials.*

Figure 8 shows an example of the fixation locations made by one participant during the task. In the example scene, the participant made a greater number of fixations on the social object and fewer on the non-social low salient object.

*Figure 8 A visual representation of the locations fixated by one participant. This condition featured a low salient non-social object and a high WM load. Fixations started at the centre of the picture and attention moved to the social object, followed by the non-social object.*

### *4.8.2 The effect of working memory load on fixations to the high and low salient non-social object*

We first considered the proportion of fixations on the non-social object (see Table 4). Participant means were entered into a within-subject ANOVA with the factors of memory load (high and low) and non-social object saliency (high and low). There was a significant effect of saliency, $F(1, 44) = 4.565$, $p = 0.038$ $\eta^2 = 0.094$ indicating that participants looked more often at the higher saliency object. There was a trend towards an effect of memory load, $F(1, 44) = 2.967$, $p = 0.092$ $\eta^2 = 0.063$, with slightly more fixations on the non-social object during the high load condition. However, there was no interaction between memory load and object saliency, $F(1, 44) = 0.284$, $p = 0.597$, $\eta^2 = 0.006$. Thus, participants looked more at the non-social object when it was higher in saliency, regardless of the memory load.

| WM | High load | | Low load | |
|---|---|---|---|---|
| Saliency of non-social object | HS | LS | HS | LS |
| | Non-social object area | | | |
| Mean | 27.41 | 21.96 | 23.78 | 20.22 |
| SD | 13.12 | 15.37 | 11.32 | 12.43 |
| | Social area | | | |
| Mean | 41.54 | 41.74 | 41.82 | 41.84 |
| SD | 13.37 | 16.52 | 14.92 | 18.17 |

*Table 4 Represents the percentage of fixations on each region of interest: social and non-social object area.*

A second analysis was performed on the proportion of fixations to the social object. Participant means were entered into a within-subject ANOVA with the factors of memory load (high and low) and non-social object saliency (high and low). This revealed no effects of load $F(1, 44) = 0.008$, $p = 0.931$, $\eta^2 = 0.000$, or object saliency $F(1, 44) = 0.002$, $p = 0.966$, $\eta^2 = 0.000$, and no interaction between load x object saliency $F(1, 44) = 0.002$, $p = 0.965$, $\eta^2 = 0.000$. Thus, indicating that participants looked at the social area regardless of WM load and non-social object saliency. The percentages in Table 4 indicate that the social object was looked at more often than the non-social object, in all conditions.

When looking at the images the viewers spent a greater number of fixations on the social object. Previous research has suggested that physical saliency may have greater effects on the first few fixations, and we might expect the influence of top-down guidance and load to change over the course of viewing. To investigate this, we further calculated the probability of fixating on each ROI (social and non-social; see Figure 9) and on the two types of non-social objects (high salience and low salience; see Figure 10) as a function of working memory load for each fixation number and participant.

From the time course in figure 9., it is clear that fixations remain greater on the social region than on the non-social region, regardless of memory load, and that this advantage persists over time. Then fixations were sorted into three bins based on the ordinal number of fixations. The initial bin integrates from the 2$^{nd}$ to the 7$^{th}$. The mid bin integrates fixations from the 8$^{th}$ to the 13$^{th}$. The last bin integrates fixations from the 14$^{th}$ to the 19$^{th}$. A 3 (fixation bin) x 2 (social or non-social object) within-subjects ANOVA was conducted on the probability of fixations on the high memory load. There was a main effect of fixation bin $F(2, 10) = 12.354$, $p = 0.011$, $\eta^2 = 0.712$, indicating difference over the time. There was a main effect of object $F(1, 5) = 96.646$, $p < 0.001$, $\eta^2 = 0.951$, indicating clearly differences between the social and the non-social object. However, there was no interaction between fixation bin and object $F(2, 10) = 3.190$, $p = 0.121$ $\eta^2 = 0.389$. Another ANOVA was conducted on the probability of fixation on the low memory load. There was no effect of fixation bin $F(2, 10) = 2.853$, $p = 0.105$, $\eta^2 = 0.363$. There was an effect of object $F(1,5) = 201.783$, $p < 0.001$, $\eta^2 = 0.976$, indicating more fixation in the social object than in the non-social object. There was no interaction between fixation bin and object $F(2, 10) = .946$, $p = 0.390$, $\eta^2 = 0.159$.

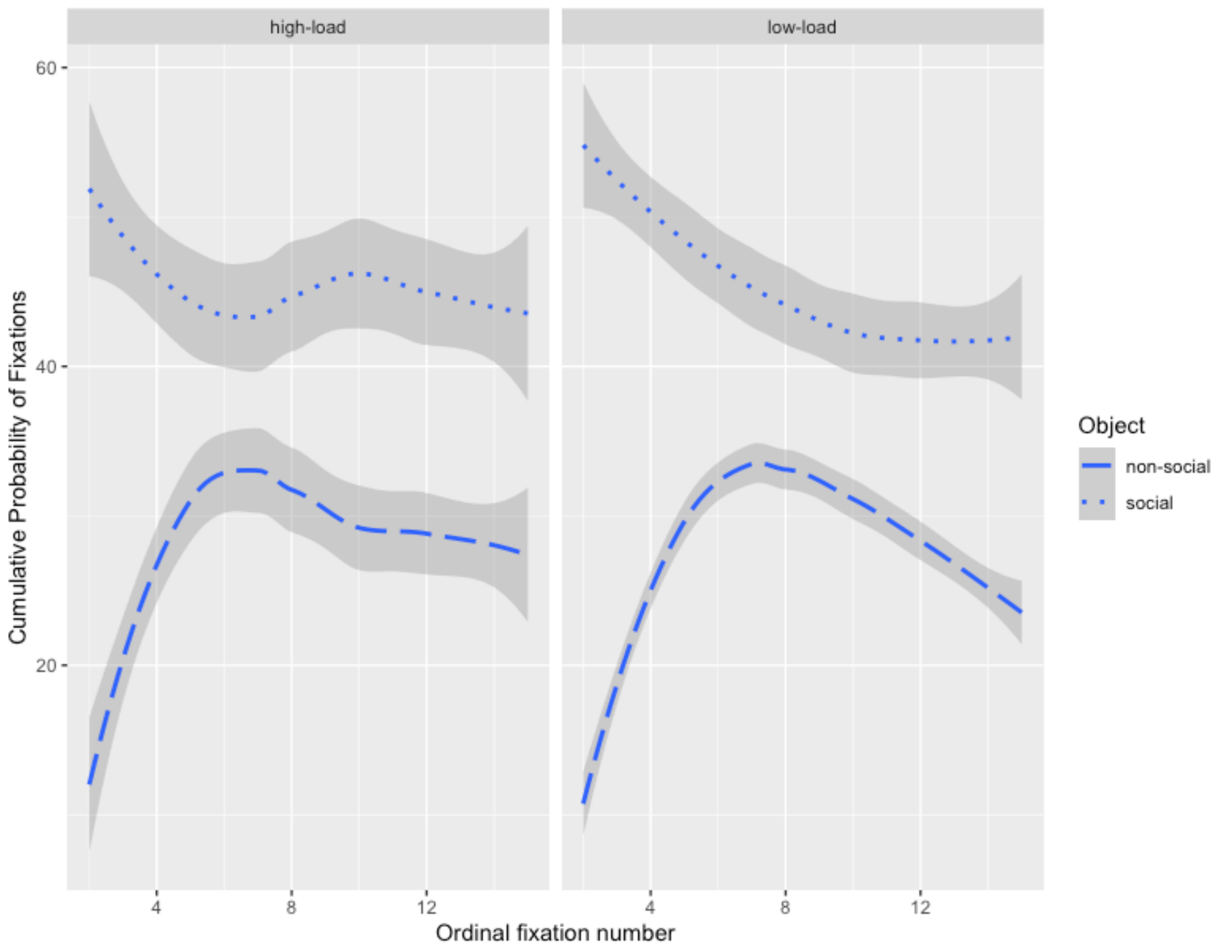


*Figure 9 The cumulative probability of fixations as a function of working memory load (high and low) and object type (social and non-social). Note that the ordinal fixation number begins at the second fixation, since the first fixation was on the centre of the scene. Lines represent the mean across participants with shading area representing the confidence interval. The x-axis is shown up until the 15th fixation, some trials would have gone longer.*

From figure 10. it is clear that effects of saliency are minor. Once again fixations were sorted into three bins (initial, mid and end). A 3 (fixation bin) x 2 (high and low salient non-social object) within-subjects ANOVA was conducted on the probability of fixations on the high memory load. There was no effect of fixation bin $F(2, 10) = 1.567$, $p = 0.266$, $\eta^2 = 0.239$. There was a trend effect of non-social object, however it did not reach significance $F(1, 5) = 5.665$, $p = 0.063$, $\eta^2 = 0.531$. There was no interaction between fixation bin and object $F(2, 10) = 3.308$, $p = 0.101$ $\eta^2 = 0.398$. Another ANOVA was run on the probability of fixations on the low memory load. There was no effect of fixation bin $F(2, 10) = 1.984$, $p = 0.216$, $\eta^2 = 0.284$. There was a trend effect of non-social object, however it did not reach significance $F(1, 5) = 5.072$, $p = 0.074$, $\eta^2 = 0.504$. There was no interaction between fixation bin and object $F(2, 10) = 0.482$, $p = 0.589$ $\eta^2 = 0.088$.

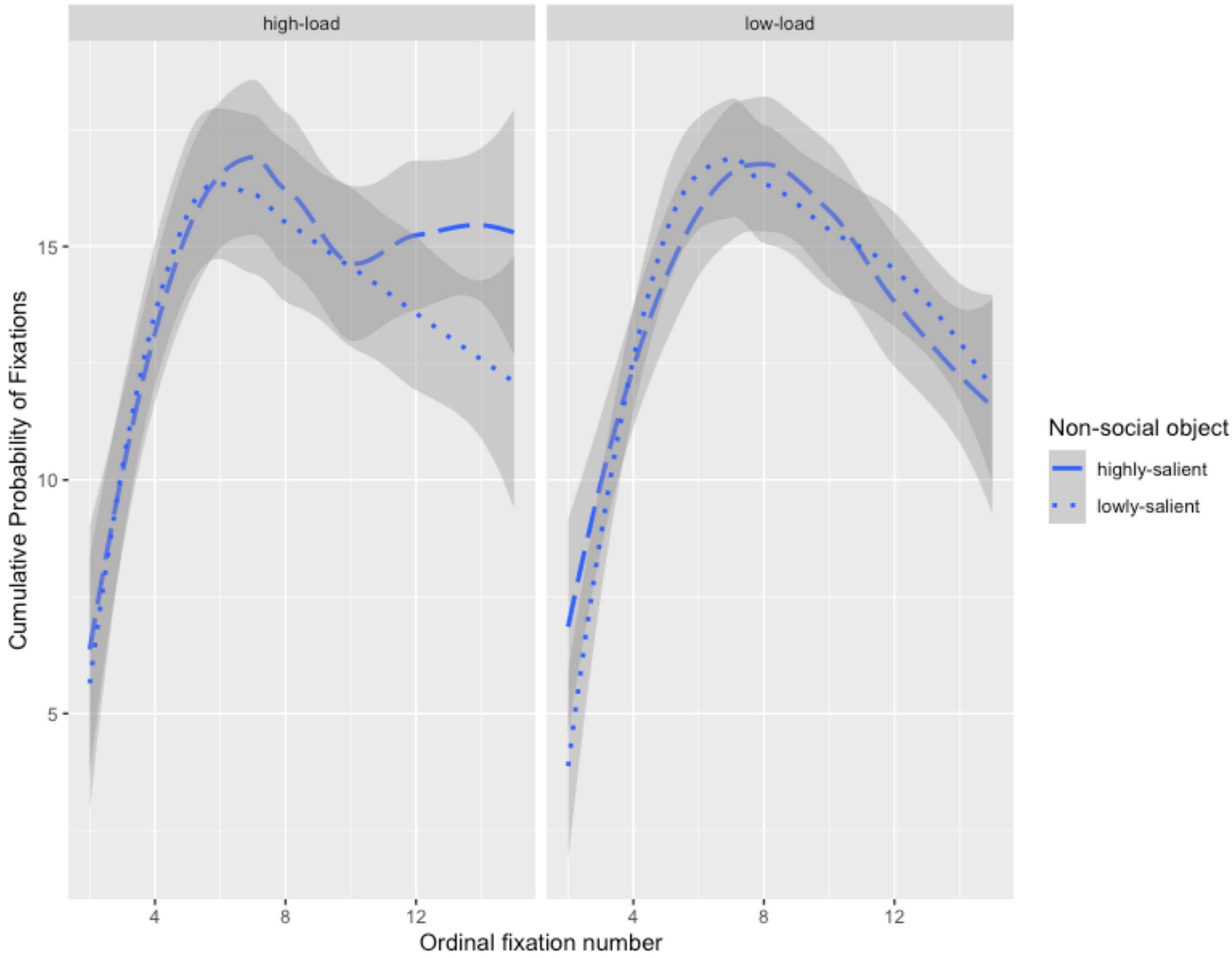


*Figure 10 The cumulative proportion of fixations as a function of working memory load (high and low) and non-social object type (highly salient and lowly salient). Note that the ordinal fixation number begins at the second fixation, since the first fixation was on the centre of the scene. Lines represent the mean across participants with shading area representing the confidence interval. The x-axis is shown up until the 15th fixation, some trials would have gone longer.*

### *4.8.3 The relationship between ADHD symptomatology and task performance*

To examine if our measures of attention in scenes were altered in those with high traits of ADHD, we correlated the total score of each participant from the ASRS questionnaire with the probability of fixations on the social area. Scores on the ASRS checklist varied from 12 to 49 and the mean score was 28.80 (SD= 8.27). The correlation values are presented in Table 5. For most variables, the relationship was weak and non-significant. However, a weak relationship was found when correlating ADHD severity with probability of fixations on the social area. The direction shows that participants with higher scores in the ASRS questionnaire fixated less often to the social area, but this was only reliable in the low memory and high salient condition. There was also a suggestive correlation between RT to the memory probe and ASRS, but only in the high load condition. This might indicate that those with ADHD traits found the WM task more difficult.

| | | Pearson R with ASRS score | p- value |
|---|---|---|---|
| PF on social | High Load HS | -0.184 | 0.226 |
| | High Load LS | -0.104 | 0.496 |
| | Low load HS | **-0.321** | **0.031** |
| | Low Load LS | -0.111 | 0.466 |
| RT | Low load | 0.130 | 0.396 |
| on correct responses | High load | 0.263 | 0.081 |

*Table 5 Correlation values for ADHD severity and the fixation variables. PF = Probability of fixations, HS= High Salient, LS = Low Salient, RT = Reaction Time, N = 45.*

## 4.9 Discussion

The current work used an image-viewing task to examine attention to social and non-social objects while memorising different loads of information. The images were also modified to investigate the role of bottom-up physical saliency. We also examined task performance related to ADHD traits. The research reviewed leads to the predictions that: (1) increased working memory load should disrupt top-down cognitive control, and therefore affect our viewing patterns, (2) our attention is biased to attend to social objects (other people) in complex settings (End & Gamer, 2019; Foulsham et al., 2010), (3) if the social bias is a consequence of default voluntary top-down goals, then it should be disrupted when memorising high loads of information, (4) if object-selection depends on top-down processes which are impaired in ADHD (Barkley, 1997; Faraone, 2000; Nigg, 2001; van Ewijk et al., 2014), then higher traits of ADHD should lead to a reduced bias towards the social object.

Increasing saliency biased the eye movement patterns such that participants looked more at the non-social object when it was highly salient than when it was not. Furthermore, working memory did not change the overarching bias to spend more time looking at the social areas. Indeed, the tendency to fixate social areas was stable across conditions. This finding is compatible with the idea that such social biases stem from automatic processes which are relatively unaffected by load (End & Gamer, 2019; Foulsham et al., 2010; Laidlaw et al., 2012).The manipulation of salience on the non-social object had an interesting effect. A greater probability of fixations are likely to be on high salient regions according to previous research, at least when there is no task requirement to look at anything else (Anderson et al., 2015; Foulsham & Underwood, 2007, 2008; Itti & Koch, 2000; Parkhurst et al., 2002; Underwood et al., 2006). Our results are consistent with the idea that bottom-up salience signals influence the control of attention. Although the high salient object attracted attention, it does not seem to affect the bias to attend to social regions.

The social advantage is interesting given that participants were only asked to look freely around the image. One explanation of the social advantage is that participants have a preference to look at people (Crouzet, 2010; Di Giorgio et al., 2012; End & Gamer, 2019; Fletcher-Watson et al., 2008; Foulsham et al., 2010) in comparison to animals or objects (Crouzet, 2010; Fletcher-Watson et al., 2008). A very rapid bias towards images of people has been reported to emerge even 100 ms after stimulus presentation (Crouzet, 2010; Fletcher-Watson et al., 2008). Social areas may continue to hold our attention due to emotional and intentional information that can be obtained from looking at eyes or mouths (Birmingham et al., 2009; Foulsham et al., 2010). From an evolutionary perspective, monkeys and humans share a similar pattern of viewing behaviour to social objects (Guo, 2007; Guo et al., 2003; McFarland et al., 2013). Both look more to the face than the body area but attend more to the body area in a negative social context over positive social context (McFarland et al., 2013). Both monkeys and humans are better at processing the eyes than other facial features (Guo, 2007; Guo et al., 2003). Such social prioritisation has also been reported in infants (Di Giorgio et al., 2012). Our data corroborates this social prioritisation even when cognitive resources are diverted to perform a secondary memory task.

It may seem surprising that participants in our study were able to prioritise social information, even in the presence of a disruptive memory load (which, in Experiment 1, we demonstrated interfered with a basic flanker task). Social areas were more likely to be looked at, even on the first few fixations. It is possible that this rapid attention to faces, which does not seem to be disrupted by load, relies on "feedforward" processes which have been identified in cognitive neuroscience. EEG studies have reported face-responsive N170 brain activation occurring at even earliest latencies (Rossion et al., 2015). For instance, evidence shows brain activity between 120 and 400 ms after stimulus presentation that is initially widespread over the medial and lateral occipital cortices (Rossion et al., 2015). This phenomenon is also consistent with the findings of single cell studies in monkeys, which have reported that neurons in the inferotemporal cortex selective for faces have similar dynamic changes to those from the primary visual cortex, despite being conventionally activated much later in the hierarchy (Sugase et al., 1999). These neuron changes may reflect a feedforward sweep process whereby certain stimuli are processed quickly and boost "low level" responses (Epshtein et al., 2008; Lamme & Roelfsema, 2000; Riesenhuber & Poggio, 1999; Sugase et al., 1999). This process may reflect pre-attentive vision, where the visual cortex is rapidly activated from low levels to high-level areas (Lamme & Roelfsema, 2000). In brief, social areas can generate feedback to lower hierarchical level before scenes are analysed in detail, thereby altering the subsequent sweep (Lamme & Roelfsema, 2000; Sugase et al., 1999).

In understanding our results it is also useful to consider the spectrum of attentional control view (Benoni & Ressler, 2020). This account considers two scales: volitional and temporal. The volitional scale emerges from explicit to implicit relevance whereas the temporal scale emerges from temporary to permanent relevance. Bearing this in mind, social advantage may be driven by implicit goals, but in a manner than would be located in permanent temporality. Our data suggest that in complex scenes, social objects dominate viewing patterns over salient objects, and they continue to do so even when memorising higher loads of information. This is perhaps surprising, since we might expect participants to try to avoid distraction while completing the memory task, for example by looking only in the centre of the screen or avoiding meaningful regions. There was also no reliable effect of load on number of fixations or duration of fixations, although there were slightly fewer fixations in the high load condition. This is a different pattern of results from Cronin et al., (2020), who reported effects of load on both number and duration of fixations, although this was more pronounced in a visual load than a verbal load condition. The finding that participants continue to look at people in the scene is in agreement with other research suggesting that attending to social information is rather automatic and hard to suppress (Laidlaw et al., 2012). That participants do not alter their natural fixation patterns whilst maintaining a large memory load, suggests that these task irrelevant fixations do not interfere with working memory, or that attempting to override them would be more costly than allowing their natural expression. The stimuli (images) in this experiment were more complex than in the previous chapter (single letter or circles). However, the free-viewing task may have been too simple to incorporate in a dual task situation in comparison to the flanker or singleton task. Future studies should combine memory load with an image-based task as a realistic visual search which explicitly requires scene processing.

High scores of ADHD traits were related to fewer fixations to the social object only in the low load and high salient condition. If social biases rely on a top-down process, we might expect to find a relationship between ADHD traits and fewer fixations to the social object across all conditions. Instead, any effects of ADHD traits in this experiment were small and should be interpreted with caution. If there is no such relationship, then this would confirm that top-down resources are not critical for a bias to social information to emerge. In the context of clinical traits, we suggest that individual differences and the underlying cognitive abilities are complex for understanding eye movement behaviour in scene viewing. One possibility for explaining our finding of fewer fixations on the social object is that ADHD traits may also overlap with Autism Spectrum Disorder (ASD). It has been suggested that between 15-25% of individuals with ADHD shows ASD symptoms and between 40 to 70% individuals with ASD shows ADHD symptoms (Antshel et al., 2016). Importantly, however; ASD + ADHD is associated with more severe impairments in cognitive and social behaviour when compared to ASD alone (Antshel et al., 2016; Gau & Shang, 2010).

In conclusion, we examined the effects of WM and ADHD-like traits on an image-viewing task. Our results suggest that during image viewing the social object was fixated to a greater degree than the other object across all the conditions. Saliency biased our visual attention (regardless of memory loads). However, working memory does not seem to affect overall social prioritisation. The relationship between the degree of ADHD-like traits and scanning behaviour was small and only detected on the number of fixations to the social object in the high salient, low load condition. Such findings suggest that attending to a social area in complex stimuli is surprisingly not dependent on the availability of default voluntary top-down resources.

# Chapter 5
# The effects of Visuospatial Working Memory Presentation on an image-viewing task and ADHD

**Abstract**

In the previous chapter, there was no effects of memory load on the social areas. In this chapter, I study whether memorising different loads and presentations of visuospatial information might affect attending to the social and non-social object. while also investigating individual differences in ADHD traits. As in the previous chapter, I measured the degree to which fixations targeted each of two crucial objects: (1) a social object (a person in the scene) and (2) a non-social object of higher or lower physical salience. The results showed that during image viewing the social object was fixated to a greater degree than the non-social object. This social biased was stronger when low loads of visuospatial information were presented during a simultaneous task. The relationship between the degree of ADHD-like traits and the task performance was small and detected only in high salient high load condition). These results showed that the social prioritisation depend on the availability of perceptual resources.

## 5.1 Introduction

Recall, WM is conceptualised as the temporary online maintenance and/or manipulation of information to be used towards a specific goal (Baddley & Hitch, 1974; Proskovec et al., 2019). The visuospatial WM comprises two subcomponents: the visual and the spatial (Baddley & Hitch, 1974). Research suggested that visuospatial WM is closely related to spatial selective attention (Awh & Jonides, 2001; Sreenivasan & D'Esposito, 2019; Van der Stigchel & Hollingworth, 2018). Specifically, this account suggests that mechanisms of spatial attention are recruited as a rehearsal function to maintain information active in WM (Awh & Jonides, 2001). The biased competition model also suggest this close relationship between WM and selective attention (Desimone & Duncan, 1995). Based on this account, first, there is an activation of a mental representation or a target template (considering colour, texture or shape) (Bundesen, 1990; Duncan & Humphreys, 1989). After, the selection occurs when there is a match between the target object and a target template (Desimone & Duncan, 1995). Some others studies have used the inhibition of return (Posner et al., 1985) phenomenon and suggested that visuospatial WM is the preparation to perform an action (Godijn & Theeuwes, 2002; Theeuwes et al., 2003; Van der Stigchel & Hollingworth, 2018). Recent developments indicate that the relationship between spatial attention and visuospatial WM comes from the need to allocate attention to relevant locations across delay (Van der Stigchel & Hollingworth, 2018).

This chapter is concerned about whether the effects of maintaining high and low loads of visuospatial representations have an effect during an image-viewing task. Furthermore, this study examines whether a simultaneous and a sequential presentation involve common processes during the image-viewing task. As in the previous experiment, the image-viewing task consider a social and non-social element with high and low salience information.

### 5.1.2 Do different types of memory loads disrupt search efficiency?

The extent to which maintaining information in the WM and successfully search for a target while ignoring irrelevant stimuli is central to our understanding of visual attention. It is well known that the facility to search for a target depend on some degree to bottom-up properties or top-down guidance (Olivers et al., 2006; Theeuwes, 2004; Theeuwes & Failing, 2020). On the other hand, distractor rejection depends on some degree to cognitive and perceptual load. (Konstantinou et al., 2014; Konstantinou & Lavie, 2020; Lavie et al., 2004). The memory-driven attentional capture hypothesis suggests a stronger effect for distractors when matched the content of memory over irrelevant colour distractors for the visual WM. But their evidence does not support the same findings for the verbal working memory (Olivers et al., 2006) An influential theory of WM, the load theory, suggests when increasing loads of information are held in the WM, irrelevant stimuli often intrude even the effort to ignore them during a discrimination task (Konstantinou & Lavie, 2020; Lavie et al., 2004). The authors also suggested opposite effects for cognitive and perceptual load on stimulus detection (Konstantinou et al., 2014; Konstantinou & Lavie, 2013, 2020). For instance, (Konstantinou & Lavie, 2013) asked participants to remember the colour and location of squares (experiment 1) and a set of digits (Experiment 2) during a delay period. In the delay period, participants also performed a visual search task while detecting a shape in the periphery. They found that during the search task, detection sensitivity was decreased when memorising high loads of squares but was increased when memorising high loads of digits. These results provide a clear evidence of an effect equivalent to that of perceptual load in detection sensitivity. Oh and Kim, (2004) found a difference in search performance between spatial and non-spatial working memory. They asked participants to perform a dual task (a memory and a search task) with a control condition (only search and only memory). In the memory task, participants memorised and array with locations (spatial) and colours (non-spatial). In the search task, participants reported whether an upright 'L' was presented or not in the array with different set sizes (four, eight and twelve). They found that search load affected the maintenance of spatial but not visual information. Together these studies suggest that loading information in spatial memory troublesome the search efficiency. Likely due to spatial control of attention and/or maintain a memory of searched locations.

Findings regarding the brain activation on visuospatial and verbal WM tasks support the claim that different brain areas account for these processes (Ahmad et al., 2017; McFarland et al., 2013; Miller & D'Esposito, 2005; Sreenivasan & D'Esposito, 2019). McNab et al., (2008) examined brain activation using both verbal and visuospatial WM tasks. In the verbal WM, participants memorised a serial presentation of 5 letters displayed for 500 ms. The cue stimulus consisted of a number that referred to the serial position in the stimulus sequence and participants were asked to respond with a yes/no whether the number matched the letter. In the visuospatial WM, participants were asked to memorise the location of 5 yellow circles presented sequentially in a 4 by 4 grid. The cue was a number between 1-5 referring to the serial position, and participants indicated whether the cue matched or not with a probe location.

The authors identified an area (right inferior frontal gyrus) to show commonalities between the verbal and visuospatial WM tasks, suggesting that both the verbal and visuospatial WM share cognitive mechanisms. (McNab et al., 2008). Cronin et al., (2020) asked participants to look at scenes while memorising verbal (seven letters) and visual (seven colours) information and when not. They found that participants fixate less when having something to memorise regardless the type of WM than when not. In a series of recognition tasks, Lecerf and de Ribaupierre, (2005) asked participants to memorise a pattern of locations either in a sequential (ordered or random) or simultaneous order. Results showed that performance in the sequentially presented in a random order were the worst in comparison to the sequentially presented ordered and simultaneously presentation (Lecerf & de Ribaupierre, 2005). Furthemore, Ahmad et al., (2017) examined stimulus distance (near vs far) and presentation (simultaneously vs sequentially) on WM. Participants memorised two items and indicated after from a colour wheel the colour of the probed item. They found that items presented with proximity had lower WM precision in the simultaneous presentation. Whereas in the sequential presentation, they found that first item is more likely to be disrupted if the second item is presented close to this.

We aim to study the extent to which sequential and simultaneous presentations of visuospatial WM with different loads of information may affect visual attention. Research on visuo-spatial working memory a simultaneously presented grid of locations, is often thought to be retained as a type of pattern, or global configuration. In contrast a sequentially presented set of locations, are thought to depend on "spatial processes" where these spatial processes are more likely to recruit eye-movement based rehearsal (Ahmad et al., 2017; Lecerf & de Ribaupierre, 2005). These reviewed studies typically resorted to a recalling number position procedure which involves sequential processing. In this study, we only asked participants to recall whether the locations were previously presented or not by using an image-viewing task to address the question of whether social (a person embedded) and a non-social content may affect overall visual attention.

There is little work understanding the effects of WM load and eye movements in social contexts (Bianchi et al., 2020; Hayward & Ristic, 2013; Pecchinenda & Petrucci, 2016). For instance, the work of Biachi et al, examined if asking participants to discriminate between letters heard previously (or not) while walking through a corridor might affect eye movements in a social context. In this study, social context is measured as a person be seated and allocated in the visual field of the participant (or not, in some conditions). The authors analysed eye movement behaviour in terms of the number of fixations a participant made to the social contexts, and how far the participant was from the social context. They found that participants looked less to the social context when required to perform the discrimination task than when not. They found that participants tend to look at the body area to a greater degree when they were close to the social context than when they were far. Similarly, when examining the effects of WM on gaze cueing, it has been reported a reduction in the gaze cueing effect by high cognitive load (Hayward & Ristic, 2013; Pecchinenda & Petrucci, 2016). Although these studies suggest that social context is modulated by cognitive load neither experimentally manipulated salience nor visuospatial presentations have been examined before. These investigations are essential to understand since different loads presentations might have an impact on our visual attention.

We have reviewed how visual attention and visuospatial WM are closely related. We also presented findings on how visuospatial WM might be disrupted by the different presentations and when facing a social stimulus. In this study, we used complex pictorial stimuli which included a social and a non-social object with high and low saliency. Previous studies on visual attention have shown a short-lived salient effect on the initial fixations on search tasks (Anderson et al., 2015; Foulsham & Underwood, 2007; Itti & Koch, 2000; Theeuwes, 2010; Underwood et al., 2006; van Zoest et al., 2004; van Zoest & Donk, 2005), and with task demands (Foulsham & Underwood, 2007; Underwood et al., 2006). Additionally, research have reported a stronger bias to socially-relevant stimuli (a person or faces) in an image (End & Gamer, 2019; Flechsenhar et al., 2018; Foulsham et al., 2010; Laidlaw et al., 2012; Laidlaw & Kingstone, 2017). Here, we investigate whether guidance to social and non-social objects with high and low saliency would be disrupted by visuospatial WM with different types of presentations (sequentially and simultaneously).

### *5.1.3 The effects of ADHD traits on visual attention and WM*

Recent research on ADHD traits has shown abnormal responses in sustained attention and WM (Jang et al., 2020; Panagiotidi et al., 2017). For instance, (Jang et al., 2020) examined visuospatial WM using event-related potentials (ERPs) in undergraduate students. They found slower reaction times for the group with traits of ADHD relative to the control group. Also, the authors reported abnormalities in neural oscillation associated with WM. Furthermore, it has been reported that during an image viewing task, participants with ADHD traits tend to fixate to a greater degree to the upper area of the screen with short transitions than those with non-traits (Hayes & Henderson, 2018). In (Forster & Lavie, 2016) study, they examined the individual differences in ADHD traits and distraction (in the performance of an attentional task). They found that higher scores of ADHD were associated with distractor interreference during the performance of two task (letter-search and name-classification). The interesting results were that higher perceptual load eliminate distraction regardless of ADHD scores. These findings indicate impairments in visual attention and working memory in traits of ADHD within the general population. However, it seems that higher (vs low) perceptual loads might reduce ADHD severity.

The previous chapter reports that both social and salient elements are not affected by verbal WM loads. We provided evidence of social prioritisation regardless of the amount held in WM. However, the effects of visuospatial WM load and presentation on image viewing have not yet addressed. In this thesis it was important to examine too whether any presentation or loads in visuospatial WM interfere with this social advantage. Thus, the main aim of the present study examined the effects of visuospatial WM loads on image-viewing. We also examined the extent to which spatial patterns of dots presented sequentially (Experiment 4) and simultaneously (Experiment 5) might affect overall the performance of visuospatial WM and viewing patterns on an image presentation. According to the load theory of selective attention, (Konstantinou et al., 2014; Konstantinou & Lavie, 2013, 2020; Lavie et al., 2004; Lavie & Tsal, 1994) loading simultaneous visuo-spatial working memory primarily creates a perceptual load, whereas a sequential load creates a larger load on the cognitive control process. We expect a reduction in the social advantage in the high simultaneous load condition as an effect of perceptual load. Such that under conditions of reduced availability of perceptual resources social stimuli capture attention to a reduced extent. This might be also the case when facing the non-social high salient object but not in the low salient object. Furthermore, we aimed at studying the relationship between the traits of ADHD and the performance of the task. If high simultaneous load condition is an effect of perceptual load and perceptual load is linked to distractor reduction (Forster et al., 2014; Forster & Lavie, 2009, 2016; Lavie et al., 2014). Then ADHD traits should be related to the performance in the high sequential load condition but not in the high simultaneous load condition.

## 5.2 Experiment 4

The purpose of experiment 4 was to study the effects of memorising sequential information and to understand how social and saliency might affect visual attention. Furthermore, we examined the relationship between ADHD individual differences and individual differences of viewing patterns. Therefore, we considered the probability of fixating to the social and non-social object with high and low saliency, performance in high and low loads of the VWM, and the scores from the ASRS questionnaire (Kessler et al., 2005), to determine the degree of ADHD symptoms.

## 5.3 Method

## 5.4 Participants

We tested 30 participants (ages 18 – 32, *M = 20.13 (SD = 2.94)* years, 21 females).

## 5.5 Task and stimuli

This task was an adapted version of McNab, Leroux, Strand, Thorell, Bergman, and Klingberg, (2008). Each trial started with a fixation dot displayed for 500ms. After, a 4 * 4 grid was displayed and either one (low load) or six (high load) different sequential locations were presented; 2000ms for the low-load and, 333 for each of the six locations in the high-load. In the high-load condition, the locations were presented in a short delay to ensure all locations are presented at the same time as the low-load. For both loads the locations were chosen at random order with no location repetition, followed by a fixation point presented for 500ms. Next the picture display was shown for 5000 ms. Participants were instructed to look freely to the picture. After, a probe display was presented, participants were required to respond whether the location was presented previously by pressing a keyboard response. After each response, reaction time and accuracy were visible for the participant. Participants were also encouraged to respond as fast and accurate as possible. Figure 11 illustrates the procedure underlying Experiment 4. Calibration and validation of the eye tracker was performed at the start of each session. The memory task and stimuli were the same as in Experiment 3. In the image-viewing task, the picture display was shown for 5000ms. Participants were instructed to look freely at the picture.

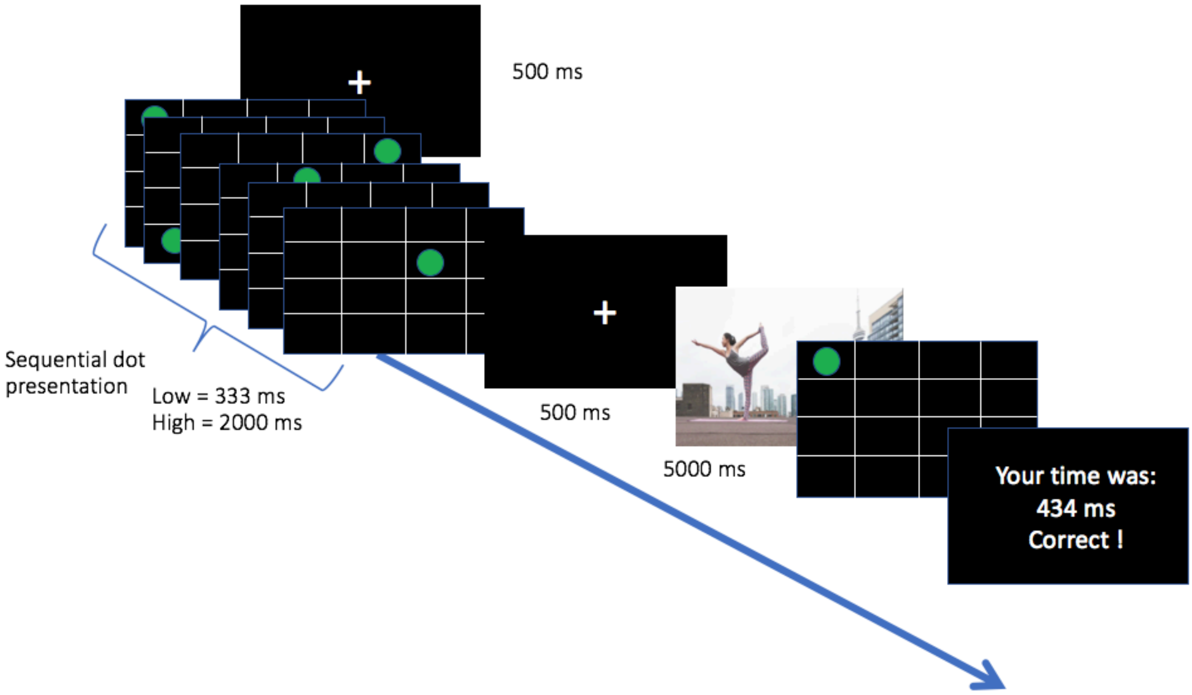


*Figure 11 Schematic representation of the stimuli and procedure of Experiment 4.*

The experiment consisted of two blocks: one green dot (low) and six green dots (high) load presentation. Each block consisted of 32 trials. Half of the participants started with the one-dot and the other half with the six-dots presentation. Within each block, there were a total of 8 different types of trial formed by a combination of the following factors: flipped image (original, flipped), memory probe (present or absent), and object saliency (high or low). Only the factors of distractor saliency and memory load were of theoretical interest. Experimental images were counterbalanced across participants such that each scene appeared in all load and saliency conditions, and was mirror reversed for half the participants to control for any biases to the left or right of the image. The experiment took a total of approximately 25 minutes.

**Design**: Two different designs were employed. The first, a two-factor design on the probability of fixating on the non-social object with memory (high and low), and non-social object saliency (high and low). The second, a two-factor design on the probability of fixating on the social object with memory (high and low), and non-social object saliency (high and low).

## 5.6 Data Analysis

Participants who scored below 50% on the memory probe were excluded from the analysis. Fixations were removed if their duration was below of 100 ms. We excluded trials with incorrect memory responses, and where the starting fixation was not recorded on the centre. We analyse only data from 20 participants.

## 5.7 Results

### *5.7.2 Behavioural data*

Accuracy from the WM task*:* The percentage of accurate response for high-load was M= 79.00, SD = 21.36, whereas for low-load was M= 89.50, SD=12.42. A paired sample t-test was conducted to compare the accuracy to the memory probe under high and low loads, t (19) =-2.103 p = .049.

Reaction Time from the WM task*:* A paired sample t- test was conducted to compare the reaction times in low and high loads. There was a significant difference in the reaction times between high-load (M = 1,003 ms, SD = 451) and low-load (M = 724 ms, SD = 248) conditions; t (20) =-2.803, p = .011. We analysed the number of fixations in the image-viewing task to have an overall idea per condition as well as the mean duration of fixations. This information is presented in Table 6.

| WM – VS | High load | | Low load | |
|---|---|---|---|---|
| Saliency of non-social object | HS | LS | HS | LS |
| N fixations/trial | 17.73 | 17.99 | 19.01 | 18.85 |
| Average fixation duration in ms | 256.65 | 231.53 | 225.30 | 227.54 |

*Table 6 Represents the mean of total number of fixations per condition*

## *5.7.3 The effect of VWM load on fixations to the high and low salient non-social object*

| WM | High load | | Low load | |
|---|---|---|---|---|
| Saliency of non-social object | HS | LS | HS | LS |
| | Non-social object area | | | |
| Mean | 24.29 | 18.11 | 24.57 | 17.24 |
| SD | 15.01 | 13.06 | 18.11 | 10.90 |
| | Social area | | | |
| Mean | 39.37 | 32.25 | 44.34 | 39.53 |
| SD | 21.71 | 21.47 | 14.85 | 15.68 |

*Table 7 Represents the percentage of fixations on each region of interest: social and non-social object area*

Table 7 shows the percentage of fixation on the social and the non-social object area in both loads of WM. These measures were entered into a within-subject ANOVA with the factors of memory load (high and low) and non-social object saliency (high and low). There was an effect of saliency; $F(1, 19) = 6.853$ $p = 0.017$ $\eta^2 = 0.265$, indicating that there were more fixations on the higher saliency object to the lower saliency object. There was no effect of memory load $F(1, 19) = 0.008$ $p = 0.930$ $\eta^2 = 0.000$, and no interaction between memory load and object saliency $F(1, 19) = 0.049$ $p = 0.827$ $\eta^2 = 0.003$. This suggested that participants looked more at the non-social object with high saliency than the low saliency regardless of the memory load. A second analysis was performed on the percentage of fixations to the social element. These measures were entered into a within-subject ANOVA with the factors of memory load (high and low) and non-social object saliency (high and low). These revealed no effects of load $F(1, 19) = 1.331$ $p = 0.263$ $\eta^2 = 0.065$ or object saliency $F(1, 19) = 2.773$ $p = 0.112$ $\eta^2 = 0.127$. Also, there was no interaction between load x object saliency $F(1, 19) = 0.121$ $p = 0.732$ $\eta^2 = 0.006$. Thus, indicating that participants looked at the social area to the same degree regardless of WM load and non-social object saliency.

To investigate whether the social and saliency effect changed over the course of viewing, we further calculated the probability of fixating on each ROI (social and non-social; see Figure 12) and on the two types of non-social objects (high salience and low salience; see Figure 13) as a function of working memory load for each fixation number and participant.

Then fixations were sorted into three bins based on the ordinal number of fixations. The initial bin integrates from the $2^{nd}$ to the $6^{th}$. The mid bin integrates fixations from the $7^{th}$ to the $11^{th}$. The last bin integrates fixations from the $12^{th}$ to the $16^{th}$. A 3 (fixation bin) x 2 (social or non-social object) within-subjects ANOVA was conducted on the probability of fixations on the high memory load. There was no effect of fixation bin $F(2, 8) = 1.579$ $p = 0.275$, $\eta^2 = 0.283$. There was a main effect of object $F(1, 4) = 40.786$, $p < 0.003$, $\eta^2 = 0.911$, indicating clearly differences between the social and the non-social object. However, there was no interaction between fixation bin and object $F(2, 8) = 1.670$ $p = 0.263$ $\eta^2 = 0.295$. Another a 3 (fixation bin) x 2 (social or non-social object) within-subjects ANOVA was conducted on the probability of fixations on the low memory load. There was no effect of fixation bin $F(2, 8) = 0.228$ $p = 0.700$ $\eta^2 = 0.054$. There was no effect of object $F(1, 4) = 0.336$, $p = 0.593$, $\eta^2 = 0.077$. However, there was an interaction between object and time $F(2, 8) = 20.397$, $p < 0.003$, $\eta^2 = 0.836$, indicating that over the time the probability of fixate to one object change.

From the time course in figure 12., it is clear that fixations remain greater on the social region especially at initial fixations than on the non-social region, regardless of memory load, and that this advantage persists over time.

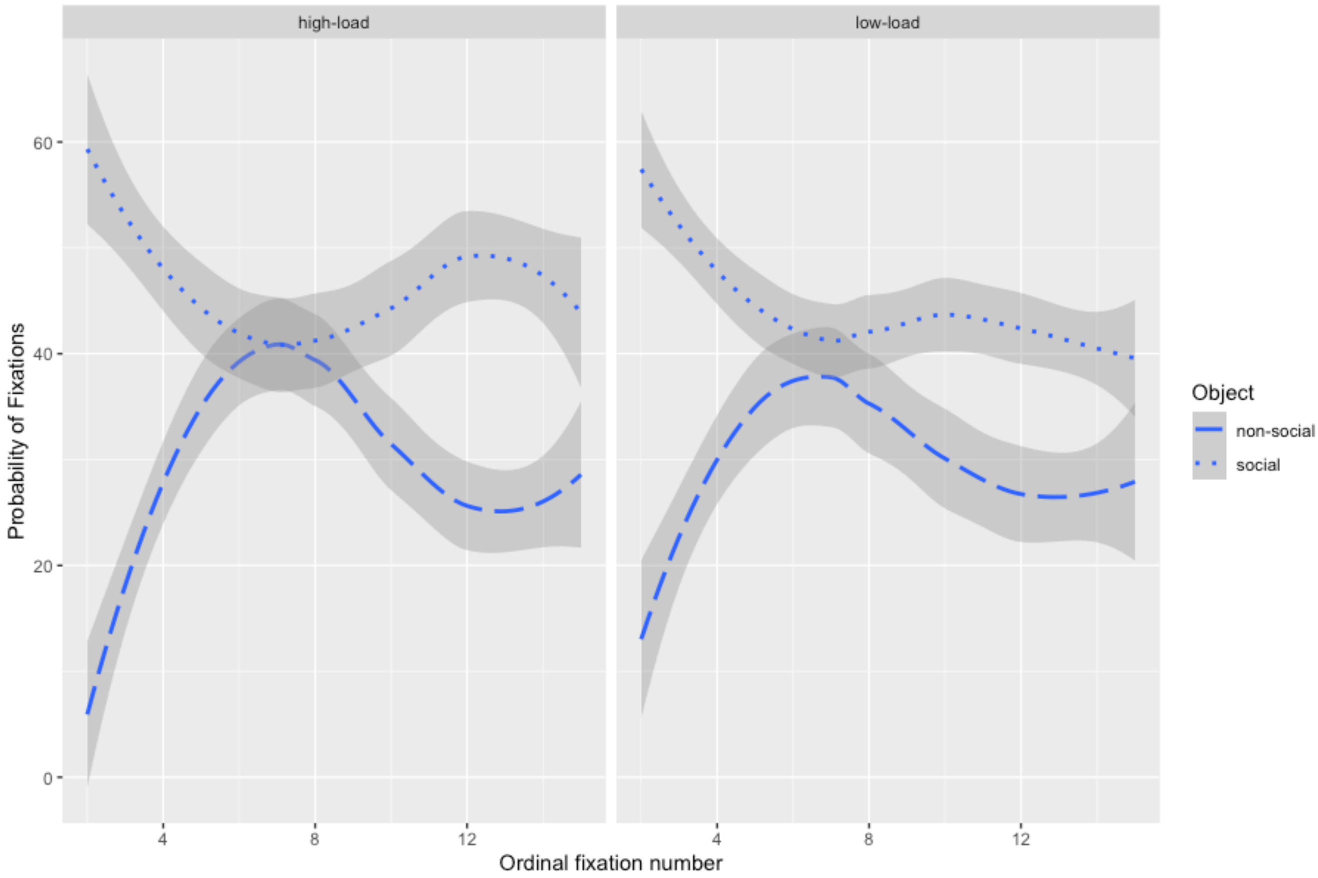


*Figure 12 The probability of fixations as a function of working memory load (high and low) and object type (social and non-social). Note that the ordinal fixation number reported is followed by the first central fixation. Lines indicate the means across participants and the shading area indicate the confidence intervals. The x-axis is shown up until 15$^{th}$ fixation; some trials would have gone longer.*

Then fixations were sorted into three bins based on the ordinal number of fixations as previously described. A 3 (fixation bin) x 2 (high and low salience on the non-social object) within-subjects ANOVA was conducted on the probability of fixations on the high memory load. There was no effect of fixation bin $F(2, 8) = 0.124$ $p = 0.792$, $\eta^2 = 0.030$. There was no effect of object $F(1, 4) = 4.540$, $p = 0.100$, $\eta^2 = 0.532$. However, there was marginal significance in the interaction between fixation bin and object $F(2, 8) = 5.900$ $p = 0.042$ $\eta^2 = 0.596$. Another a 3 (fixation bin) x 2 (high and low salience on the non-social object) within-subjects ANOVA was conducted on the probability of fixations on the low memory load. There was an effect of fixation bin $F(2, 8) = 7.129$ $p = 0.033$, $\eta^2 = 0.641$. This indicates a difference over these times. There was no effect of object $F(1, 4) = .732$, $p = 0.441$, $\eta^2 = 0.155$. There was no interaction between object and time $F(2, 8) = 2.015$, $p = 0.223$, $\eta^2 = 0.335$. From figure 13, it is clear that the salience effects are observable later on time regardless of memory load

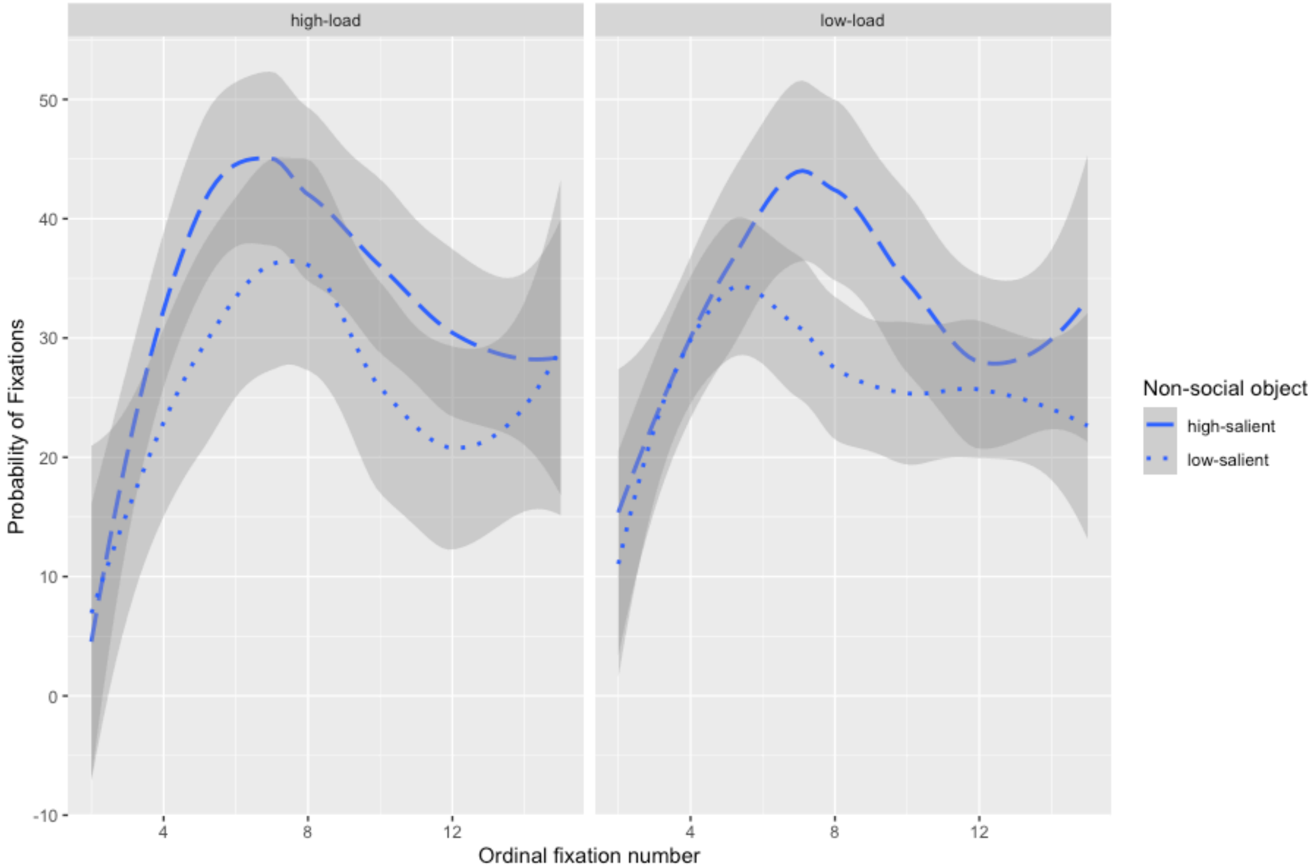


*Figure 13 The probability of fixations as a function of working memory load (high and low) and object type (high salient and low salient). Note that the ordinal fixation number reported is followed by the first central fixation. Lines indicate the means across participants and the shading area indicate the confidence intervals. The x-axis is shown up until 15th fixation; some trials would have gone longer.*

### *5.7.4 The relationship between ADHD symptomatology and task performance*

To examine if the tendency towards socially relevant objects is reduced in high traits of ADHD, we correlated the total score of each participant from the ASRS questionnaire with the probability of fixations on the social area. Scores on the ASRS checklist varied from 16 to 43 and the mean score was 29.05 (8.21). The correlation values are presented in Table 8. In all the variables, the relationship was weak and non-significant.

| | ADHD severity | Pearson R | p- value |
|---|---|---|---|
| PF on non-social object | High Load HS | 0.293 | 0.210 |
| | High Load LS | 0.314 | 0.178 |
| | Low load HS | 0.000 | 0.999 |
| | Low Load LS | 0.136 | 0.569 |
| PF on social | High Load HS | 0.258 | 0.272 |
| | High Load LS | 0.254 | 0.281 |
| | Low load HS | 0.108 | 0.651 |
| | Low Load LS | -0.230 | 0.330 |
| RT / correct | Low load | 0.237 | 0.313 |
| | High load | -0.025 | 0.918 |

*Table 8 Correlation values for ADHD severity and the fixation variables. PF = Probability of fixations, HS = high salient, LS = Low salient, RT = Reaction Time, N= 20.*

## 5.8 Experiment 5

Experiment 5 aimed to study the effects of memorising information in a simultaneous presentation. As reported by Ahmad et al., (2017) simultaneously presenting cues, make them to compete within early visual areas, harming the WM precision. Furthermore, it is important to consider that static patterns are associated with configural or 'ensemble' coding and this may place a bigger load on specifically visual memory systems concerned with coding shape or form as reported by (Della Sala et al., 1999), If that is the case, we expect to have be a stronger modulation by loads to both areas of the scene.

## 5.9 Methods

## 5.10 Participants

We tested 30 participants (ages 18 – 25, *M = 19.53 (SD = 1.45)* years, 21 females).

## 5.11 Apparatus and Stimuli

The apparatus and the stimuli were the same as in Experiment 4, except for the following changes. The locations were presented simultaneously. Figure 14. illustrates the procedure underlying Experiment 5. Calibration and validation of the eye tracker was performed at the start of each session.

**Design**: Two different designs were employed. The first, a two-factor design on the probability of fixating on the non-social object with memory (high and low), and non-social object saliency (high and low). The second, a two-factor design on the probability of fixating on the social object with memory (high and low), and non-social object saliency (high and low).

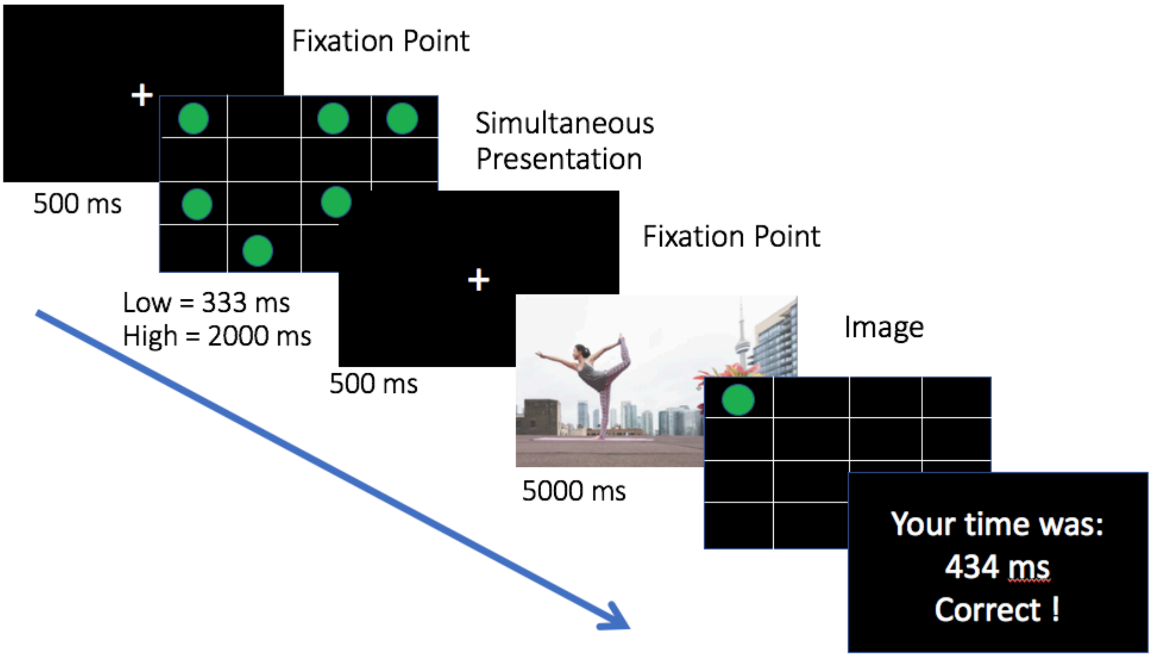


*Figure 14 Schematic representation of the stimuli and procedure of Experiment 5.*

## 5.12 Analysis and Results

The same criteria for analysis were performed as in experiment 4. The data from 21 participants were analysed.

## *5.12.2 Behavioural data*

Accuracy from the WM task*:* The percentage of accurate response for high-load was M= 78.17, SD = 22.05, whereas for low-load was M= 92.24, SD=9.85. A paired sample t-test was conducted to compare the accuracy to the memory probe under high and low loads, t (21) =-2.659 p < .015.

Reaction Time from the WM task: A paired sample t- test was conducted to compare the reaction times in low and high loads. There was a significant difference in the reaction times between high-load (M = 923ms, SD = 438) and low-load (M = 687 ms, SD = 200) conditions; t (21) =-2.283, p = .033.

## *5.12.3 General eye movement statistics*

We analysed the number of fixations to have an overall idea of the number of fixations per condition as well as the mean duration of fixations. This information is presented in Table 9.

| WM – VS | High load | | Low load | |
|---|---|---|---|---|
| **Saliency of non-social object** | HS | **LS** | **HS** | **LS** |
| N fixations/trial | 20.05 | 19.82 | 19.68 | 18.76 |
| Average fixation duration in ms | 211.62 | 220.12 | 211.54 | 236.67 |

*Table 9 Represents the mean of the total number of fixations per condition*

### *5.12.4 The effect of VWM-Simultaneously load on fixations to the high and low salient non-social object*

| WM | High load | | Low load | |
|---|---|---|---|---|
| Saliency of non-social object | HS | LS | HS | LS |
| | Non-social object area | | | |
| Mean | 20.13 | 18.73 | 23.32 | 23.96 |
| SD | 13.96 | 13.08 | 12.67 | 11.22 |
| | Social area | | | |
| Mean | 34.51 | 37.80 | 43.14 | 45.46 |
| SD | 20.39 | 23.37 | 10.37 | 11.62 |

*Table 10 Represents the percentage of fixations on each region of interest: social and non-social object area.*

Participant means were entered into within-subject ANOVA with the factors of memory load (high and low) and non-social object saliency (high and low). These revealed no effects of load $F(1, 21) = 2.147$ $p = 0.158$ $\eta^2 = 0.093$ or object saliency $F(1, 21) = 0.018$ $p = 0.895$ $\eta^2 = 0.001$. There was also no interaction between load and object saliency $F(1, 21) = 0.304$ $p = 0.587$ $\eta^2 = 0.014$. Thus, indicating that participants looked at the same extent the non-social object regardless of WM load or saliency. In a second analysis, the percentage of fixations to the social element were entered into a within-subject ANOVA with the factors of memory load (high and low) and non-social object saliency (high and low). There was a significant main effect of memory $F(1, 21) = 5.251$ $p = 0.032$ $\eta^2 = 0.200$, indicating that participants looked more often at the social object when memorising low loads of information. There was no effect of saliency $F(1, 21) = 0.624$ $p = 0.438$ $\eta^2 = 0.029$. There was no interaction between memory load and object saliency $F(1, 21) = 0.016$ $p = 0.899$ $\eta^2 =$

0.001. As in the previous experiments we calculated the probability of fixating on each ROI (social and non-social; see Figure 15) and on the two types of non-social objects (high salience and low salience; see Figure 16) as a function of working memory load for each fixation number and participant.

The same analysis was done as in the previous experiment considering the three bins based on the ordinal number of fixations. A 3 (fixation bin) x 2 (social or non-social object) within-subjects ANOVA was conducted on the probability of fixations on the high memory load. There was an effect of fixation bin $F(2, 8) = 9.290$ $p = 0.012$, $\eta^2 = 0.699$. There was no an effect of object $F(1, 4) = 3.037$ $p = 0.156$, $\eta^2 = 0.432$. However, there was no interaction between fixation bin and object $F(2, 8) = 1.670$ $p = 0.263$ $\eta^2 = 0.295$. Another 3 (fixation bin) x 2 (social or non-social object) within-subjects ANOVA was conducted on the probability of fixations on the low memory load. There was an effect of fixation bin $F(2, 8) = 11.947$ $p = 0.014$, $\eta^2 = 0.749$. There was an effect of object $F(1, 4) = 75.155$ $p = 0.001$, $\eta^2 = 0.949$. There was also an interaction between fixation bin and object $F(2, 8) = 27.931$ $p = 0.003$ $\eta^2 = 0.875$. From the time course in figure 15., it is evident that fixations were greater on the social region than on the non-social region, especially in low-loads in comparison to high-loads of memory, and that this social advantage seems to be greater in the initial fixations.

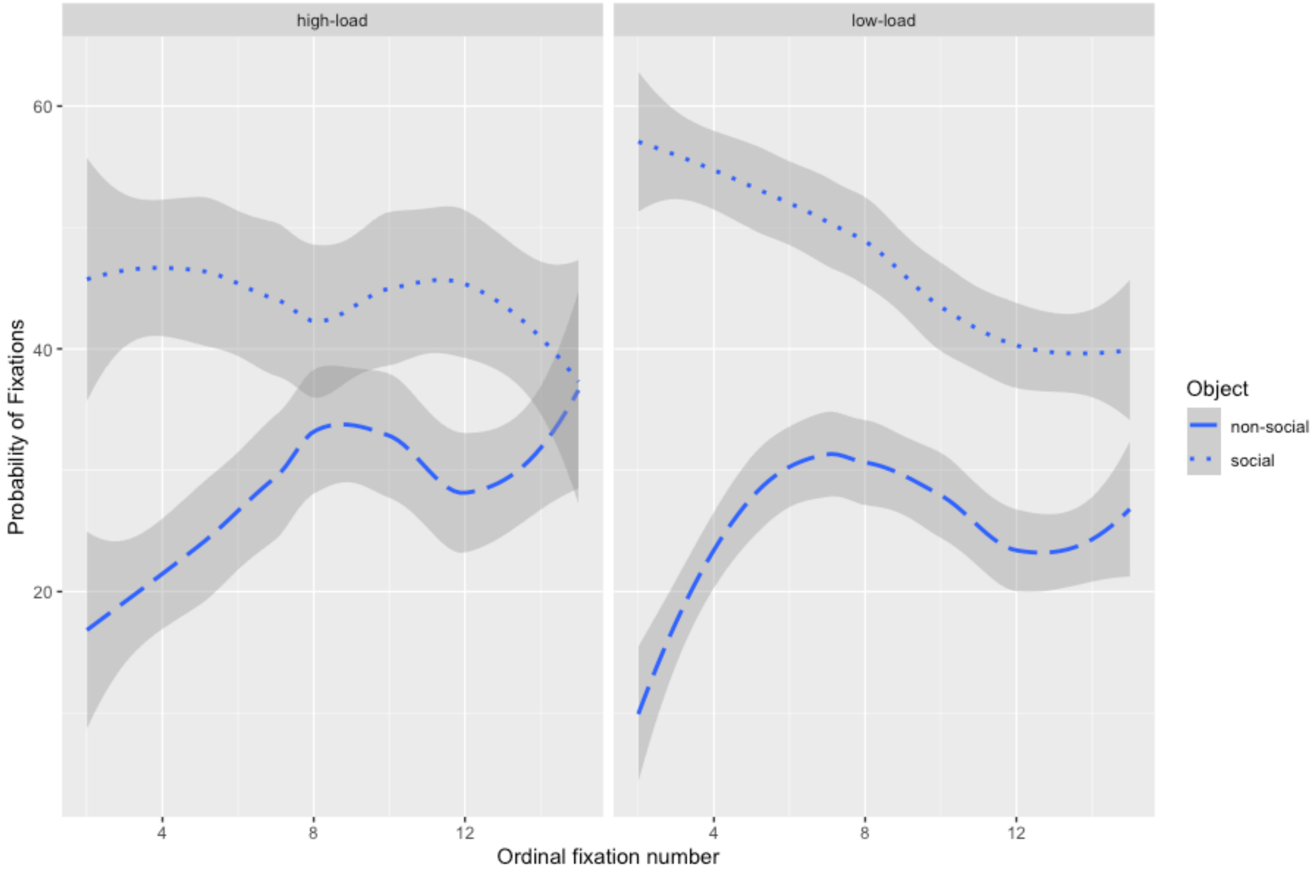


*Figure 15 The probability of fixations as a function of working memory load (high and low) and object type (social and non-social). Note that the ordinal fixation number reported is followed by the first central fixation. Lines indicate the means across participants and the shading area indicate the confidence intervals. The x-axis is shown up until 15th fixation; some trials would have gone longer.*

This time, I ran the same analysis with 3 (fixation bin) x 2 (high and low non-social salience) within-subjects ANOVA on the probability of fixations on the high memory load. There was an effect of fixation bin $F(2, 8) = 5.501$ $p = 0.033$, $\eta^2 = 0.579$. There was no effect of object $F(1, 4) = .894$ $p = 0.398$, $\eta^2 = 0.183$. There was no interaction between fixation bin and object $F(2, 8) = 3.061$ $p = 0.145$ $\eta^2 = 0.434$. Once again, these results corroborate the difference over the time whilst attending to both objects.

The same analysis was run this time with 3 (fixation bin) x 2 (high and low non-social salience) within-subjects ANOVA on the probability of fixations on the low memory load. There was an effect of fixation bin $F(2, 8) = 0.793$ $p = 0.425$, $\eta^2 = 0.166$. There was an effect of object $F(1, 4) = 4.299$ $p = 0.107$, $\eta^2 = 0.518$. There was also an interaction between fixation bin and object $F(2, 8) = 3.913$ $p = 0.097$ $\eta^2 = 0.495$. From the time course in figure 16., It is evident of a delay salience effect especially in the low load.

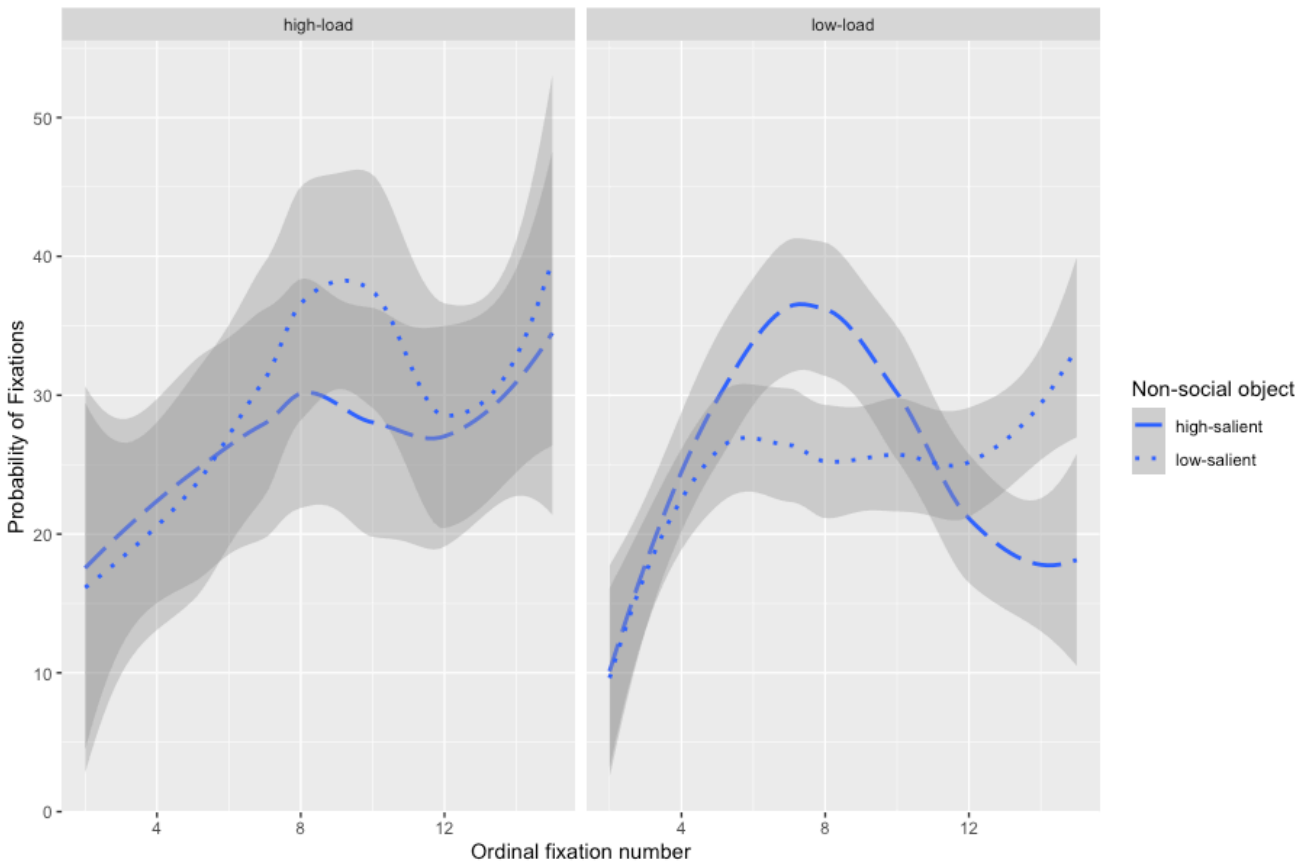


*Figure 16 The probability of fixations as a function of working memory load (high and low) and object type (high salient and low salient). Note that the ordinal fixation number reported is followed by the first central fixation. Lines indicate the means across participants and the shading area indicate the confidence intervals. The x-axis is shown up until 15th fixation; some trials would have gone longer.*

### *5.12.5 The relationship between ADHD symptomatology and task performance*

To examine if the tendency towards socially relevant objects is reduced in high traits of ADHD, we correlated the total score of each participant from the ASRS questionnaire with the probability of fixations on the social area. Scores on the ASRS checklist varied from 15 to 46 and the mean score was 31.04 (7.08). The correlation values are presented in Table 11. For most of the variables, the relationship was weak and non-significant. However, we found a relationship between probability of fixating the non-social object and high load high salient condition.

| | ADHD severity | Pearson R | p- value |
|---|---|---|---|
| PF on non-social object | High Load HS | **-0.438** | **0.042** |
| | High Load LS | -0.339 | 0.123 |
| | Low load HS | -0.026 | 0.909 |
| | Low Load LS | -0.028 | 0.902 |
| PF on social | High Load HS | -0.032 | 0.889 |
| | High Load LS | 0.251 | 0.261 |
| | Low load HS | 0.271 | 0.223 |
| | Low Load LS | -0.128 | 0.571 |
| RT / correct | Low load | 0.146 | 0.517 |
| | High load | -0.029 | 0.898 |

*Table 11 Correlation values for ADHD severity and the fixation variables. PF = Probability of fixations, HS = High Salient, LS = Low Salient, RT Reaction Time, N = 22.*

## *5.12.6 Combined analysis of experiment 4 and 5*

| WM | High load | | Low load | |
|---|---|---|---|---|
| Saliency of non-social object | HS | LS | HS | LS |
| | Non-social object area | | | |
| Mean | 22.11 | 18.43 | 23.91 | 20.76 |
| SD | 14.44 | 12.91 | 12.75 | 11.45 |
| | Social area | | | |
| Mean | 36.82 | 35.16 | 43.71 | 42.64 |
| SD | 20.92 | 22.39 | 12.56 | 13.86 |

*Table 12 Represents the percentage of fixations on each region of interest: social and non-social object area.*

Participant means for the proportion of fixations on the non-social object area were entered into mixed ANOVA with the factors of memory load (high and low) and non-social object saliency (high and low) and between subjects (Experiment 1 and 2). These revealed no effects of load $F(1, 42) = 0.968$ $p = 0.331$ $\eta^2 = 0.023$ or load and task interaction $F(1, 42) = 1.258$ $p = 0.268$ $\eta^2 = 0.029$. There was a trend of saliency $F(1, 40) = 3.399$, $p = 0.073$ $\eta^2 = 0.078$. There was no effect of task $F(1, 42) = 0.006$ $p = 0.941$ $\eta^2 = 0.000$, no effect of saliency and task $F(1, 42) = 2.890$ $p = 0.097$ $\eta^2 = 0.064$, memory and saliency interaction $F(1, 42) = 0.015$ $p = 0.904$ $\eta^2 = 0.000$ and memory x saliency x task interaction $F(1, 42) = 0.247$ $p = 0.622$ $\eta^2 = 0.006$.

Participant means for the proportion of fixations on the social object area were entered into mixed ANOVA with the factors of memory load (high and low) and non-social object saliency (high and low) and a between subjects (Task 1 and 2). There was a significant effect of load $F(1, 42) = 5.156$ $p = 0.029$ $\eta^2 = 0.114$, indicating that participants looked less often at the social object when memorising high loads of information. There was no interaction between memory and task $F(1, 42) = 0.195$ $p = 0.661$ $\eta^2 = 0.005$. There was no effect on saliency $F(1, 42) = 0.247$ $p = 0.622$ $\eta^2 = 0.006$, but a trend of saliency and task interaction $F(1, 42) =3.623$, $p = 0.064$ $\eta^2 = 0.079$. There was no effect on task $F(1, 42) =0.068$ $p = 0.795$ $\eta^2 = 0.002$. There was no interaction between memory and saliency $F(1, 42) =0.063$, $p = 0.803$ $\eta^2 = 0.001$. There was no interaction between memory x saliency and task $F(1, 42) = 0.048$ $p = 0.828$ $\eta^2 = 0.001$.

## 5.13 Discussion

The current study examined the effect of a high or low visuo-spatial WM load on eye movement behaviour when free viewing scenes. The images were modified in salience (high and low) to examine the role of bottom-up factors during the scene-viewing task. Furthermore, we examined the individual differences in task performance related to individual difference in ADHD traits. The research reviewed led to the predictions that: (1) high simultaneous load presentation should be more disruptive as a consequence of perceptual load, thus reducing the social advantage (2) increased saliency should lead to increasing fixations, (3) increased ADHD traits should lead to poor performance in the high sequential load presentation, but not in the high simultaneous load presentation. This study reported a difference in how a visuospatial WM load modulates visual attention, depending on the presentation mode. Increasing a simultaneously presented visuo-spatial working memory load reduced the number of fixations participants had at the social object, and this effect was present early in time.

The results from Experiment 4 only confirmed that high salient areas attract fixations to the non-social object. There are some considerations when analysing these results in terms of salience and social information. Although, the analysis illustrating the course of the fixations in the scene-viewing showed greater fixations to the salient effect in a later time initiating between the 5th and 8th fixation. These results do not support the attentional capture via bottom-up information. In fact, these effects to be considered as a salience prioritisation should have been observed in the first second of the image presentation, that is between the 2nd to the 4th fixation and not later (Awh et al., 2012; Theeuwes, 2010; van Zoest et al., 2004; van Zoest & Donk, 2005). If it is not salience, then what it is? Rudkin et al., (2007) argued that the spatial sequential tasks (involving recall in order) tap executive control processes to a greater extent than simultaneous tasks. It is possible that the sequential presentation led to a significant increase of strategic eye movement control exercised by participants over the encoding and rehearsal, as a requirement in the construction of a mental configuration (Della Sala et al., 1999; Rudkin et al., 2007).Interestingly, however, this construction in the rehearsal and encoding does not seem to affect much to the social prioritisation which remain between %39 to %44 with no difference between loads of memory. These percentage has been also reported in the previous chapter. Such data suggest that this social prioritisation remain stronger when facing a simultaneous presentation of a WM task.

The results from Experiment 5 seems interesting regarding the presentation and the social advantage. The simultaneous presentation is in fact reported slightly quicker reactions times in both WM loads than the sequential presentation. These data do not seem to be in favour or contradict the difficulty of presenting sequential information as previously reported(Ahmad et al., 2017). However, in this experiment there is null effects of salience information supporting the results from previous work and chapter (Anderson et al., 2015; Foulsham & Underwood, 2007; H. Zhang et al., 2020a). Nevertheless, the social effect seems to be at some degree affected by increasing the visuo-spatial working memory load. This effect is also observable when combining the results from experiment 4 and 5. Therefore, it confirmed that there is a social prioritisation in a scene-viewing task but only reported in low loads of visuospatial WM. These suggesting that memorising high loads of visuospatial information does affect looking at the social content as previously reported (Bianchi et al., 2020). Furthermore, this simultaneous presentation corroborates our predictions of a reduction in the social advantage and can be explained as a consequence of high perceptual loads (Konstantinou et al., 2014; Konstantinou & Lavie, 2013, 2020; Lavie et al., 2004; Lavie & Tsal, 1994). It is possible that the social advantage depends on the availability of perceptual resources, when these are allocated to the memory items, less is available for processing the scene, and the social advantage is reduced. Our data suggest that in complex scenes, social objects dominate viewing patterns over salient objects, regardless of the presentation. Although, when memorising high loads of visuospatial WM this social advantage might be compromised, because the social advantage depends on available "perceptual load", but not available cognitive load, see earlier experiments.

This chapter also reports a relationship between percentage of fixating the non-social object and high load high salient condition. Interestingly, the effects found in the sequential load presentation (but not in the high simultaneous load presentation) are consistent with the Load theory that suggest increased perceptual load reduce distraction (Forster et al., 2014; Forster & Lavie, 2009, 2016; Lavie et al., 2014). Note that we did not find any other relationship across the conditions with ADHD traits. Therefore, our results caution the use of complex tasks in the understanding of the individual difference in ADHD. The visuospatial WM task was more sensible to detect individual differences in ADHD than in the previous chapter since much of the work in ADHD impairments are assessed examining the visuospatial WM sketchpad.

In conclusion, we examined the effects of WM loads and presentation on an image-viewing task. Also, we examined the relationship between task performance and individual differences. The results show that during image viewing the social object was fixated to a greater degree than the other object (as reported in the previous chapter), but surprisingly this social biased was stronger when low loads of visuospatial information were presented during a simultaneous task. The relationship between the degree of ADHD-like traits and the task performance was small and detected once to the non-social object (in high salient high load condition). These results show that the social prioritisation depend on the availability of perceptual resources.

# Chapter 6
# The effects of instructions and individual differences in attention on image-viewing

**Abstract**

In this chapter, I examine the effects of task instructions on looking at the social and non-social element with higher and lower physical salience. By using the 'do not look' (DL) paradigm, I hypothesised that if the bias to look at the social element is a consequence of an automatic response, and this element is stronger than what may be capturing attention to the non-social element, then performance in the DL: social condition should be worse (i.e., more errors should be made) than performance in the DL: non-social condition (this effect should also be observable in earlier fixations). Otherwise, performance in the DL: social condition should be comparable to that demonstrated in the DL: non-social element. Furthermore, I examine whether the performance of the task was related to ADHD and Mind-Wandering traits.

## 6.1 Introduction

We, as human beings, have a characteristic tendency to look at social information i.e., other individuals (End & Gamer, 2019; Flechsenhar et al., 2018; Foulsham et al., 2010; Laidlaw & Kingstone, 2017; Vogel et al., 2001). Faces (especially the eyes) are prioritise among other visual stimuli, a fact that becomes clear in social settings (Capozzi & Ristic, 2021; Foulsham et al., 2010; Foulsham & Sanderson, 2013). This social prioritisation has led to further examine the cause of it (Laidlaw & Kingstone, 2017; Ristic & Kingstone, 2005). For instance, Laidlaw and Kingstone, (2017) asked participants to perform three different conditions while memorising images of static faces: do not look at the eyes, do not look at the mouth and free-viewing. After, they were asked to recognise the encoded face. Results showed that participants' performance was better at discriminating faces in the free-viewing condition over the restricted ones. That is, participants made more errors during the 'do not look at the eyes' condition (i.e., they couldn't help looking at the eyes) than in the 'do not look at the mouth' condition. Furthermore, End and Gamer (2019) asked participants to direct their fixations to the socially relevant areas (head and body). Result showed more fixations in the head in comparison the body. In previous chapters, I have examined the extent to which social information is modulated by WM manipulations. In each experiment, I have reported a very strong bias to the social area. However, in this chapter, I will further examine how automatic is this process by implementing the same methodology as in Laidlaw and Kingstone, (2017).

Research has also examined Mind-Wandering (MW) from a content-based perspective by asking participants to self-monitor their shifts away from their thoughts to an ongoing task or activity (Christoff et al., 2016; Foulsham, Farley, et al., 2013; Risko et al., 2012; H. Zhang et al., 2020b, 2020a). MW is referred to as the times when attention and the contents of thoughts shift away to external sources or internal thoughts or feelings (Smallwood & Schooler, 2015). Research has identified two types of MW: intentional and unintentional. If, for instance, on your commute, you are thinking about what to prepare for dinner; these self-generated thoughts are the intentional type. If, while in a group conversation, you spontaneously lose the thread, this spontaneously performing action is the unintentional type (Christoff et al., 2016). Researchers often simply ask participants whether they were on-task or mind-wandering (e.g., Zhang et al., 2020b). By using this approach, it has been suggested that task-unrelated thoughts accounts for around 30 to 50 % of the task (Foulsham, Farley, et al., 2013; Risko et al., 2012) Also, there is an increment in the MW responses over the course of the task (Foulsham, Farley, et al., 2013; H. Zhang et al., 2020a). In Zhang et al (2020) study, they asked participants to look at some scenes (with high and low salient features) while reporting their attentional state i.e., on-task, intentional MW, or unintentional MW. Zhang et al research is fundamental to understand whether salience features might bias the visual deployment in scene-viewing task. They provided evidence that individual fixations prioritise salient regions during MW. But Zhang et al., (2020) also reported that participants do not seem to have sufficient fixations to cover these regions compared to when they were on-task. However, some of the considerations to account when following this type of approach are the individual differences and the trial-to-trial differences as well. It may be possible that some of the participants' current thoughts are missed when on-task

MW has been suggested to resemble symptoms of disorders such as ADHD, anxiety, depression, and Obsessive-Compulsive Disorder (Figueiredo et al., 2020; Hobbiss et al., 2019; Seli et al., 2017). The current study examines the individual differences in traits of MW and ADHD in the performance of an image-viewing task. Since the 'do not look' instructions require some cognitive control, the study of MW and ADHD symptoms might be relevant because they are about controlling attention.

### *6.1.2 ADHD and mind wandering*

Some of the characteristic behaviours of ADHD include ceaseless mental activity, constantly on the go thoughts, a mind constantly full of thoughts, or jumping between different ideas (Mowlem, Skirrow, et al., 2019). In patients with ADHD, research has suggested that MW is associated with the inattentive presentation (Jonkman et al., 2017) and with traits of anxiety but not depression (Figueiredo et al., 2020). Furthermore, Seli et al., (2015) demonstrated that these traits are also reported across the community and the clinical samples. However, when the authors assessed the specificity of MW intentional and unintentional symptomatology, they found that unintentional MW is associated with ADHD symptoms across the community and the clinical. Further studies have revealed that those participants with high traits of ADHD are more likely to have MW events that are disastrous and affect their quality of life (Figueiredo et al., 2020; Franklin et al., 2007; Helfer et al., 2021; Jonkman et al., 2017).

## 6.2 Experiment 6

The main aim of the present study was to examine the effects of task instructions on looking at the social and non-social element with higher and lower physical salience. We used the ‘do not look’ (DL) paradigm and hypothesised that if the bias to look at the social element is a consequence of an automatic response, and this element is stronger than what may be capturing attention to the non-social element, then performance in the DL: social condition should be worse (i.e., more errors should be made) than performance in the DL: non-social condition (this effect should also be observable in earlier fixations). Otherwise, performance in the DL: social condition should be comparable to that demonstrated in the DL: non-social element. Furthermore, we expect that the high salient non-social element should facilitate attentional capture by avoiding a social element distraction. If that is the case performance in the DL social should be worse (more errors) in the lower salient non-social element, but not in the higher salient non-social element. In the current study, the ADHD and MW traits were also assessed. To this end, we asked participants (undergraduate psychology students) to complete questionnaires assessing (1) levels of MW (assessed with the MEWS; (Mowlem, Skirrow, et al., 2019) and (2) ADHD symptomatology (assessed with the ASRS; Kessler at al., 2005). We hypothesised that participants with higher traits of ADHD or MW should find it harder to follow instructions as a consequence, they should perform with more errors in the restricted conditions over the free viewing condition. Furthermore, if social impairments are a characteristic behaviour in ADHD, then we expect that ADHD traits to be related to an avoidance behaviour (i.e., lesser fixations) to the social object, but not in the non-social object in a scene. In addition, if MW and ADHD have associated symptoms, then we expect to find the same behavioural response (i.e., the same effect across the symptoms of MW).

## 6.3 Materials

## 6.4. Participants

We tested 30 participants (ages 18 – 25, *M* = 19.53 years, 21 females).

## 6.5 *Apparatus* and Stimuli

The apparatus is described in chapter 2. Before the experiment, participants were required to complete the Adult ADHD Self-Report Scale (ASRS; Kessler at al., 2005) and the Mind-Excessively Wandering Scale (MEWS; Mowlem et al., 2019). The ASRS and MEWS are described already in Chapter 2.

Figure 17 illustrates the procedure in Experiment 6. Calibration and validation of the eye tracker was performed at the start of each session. We used a modified version of the task from Laidlaw et al., (2012) in which participants were asked not to look at specific areas of an image while their eyes were tracked.

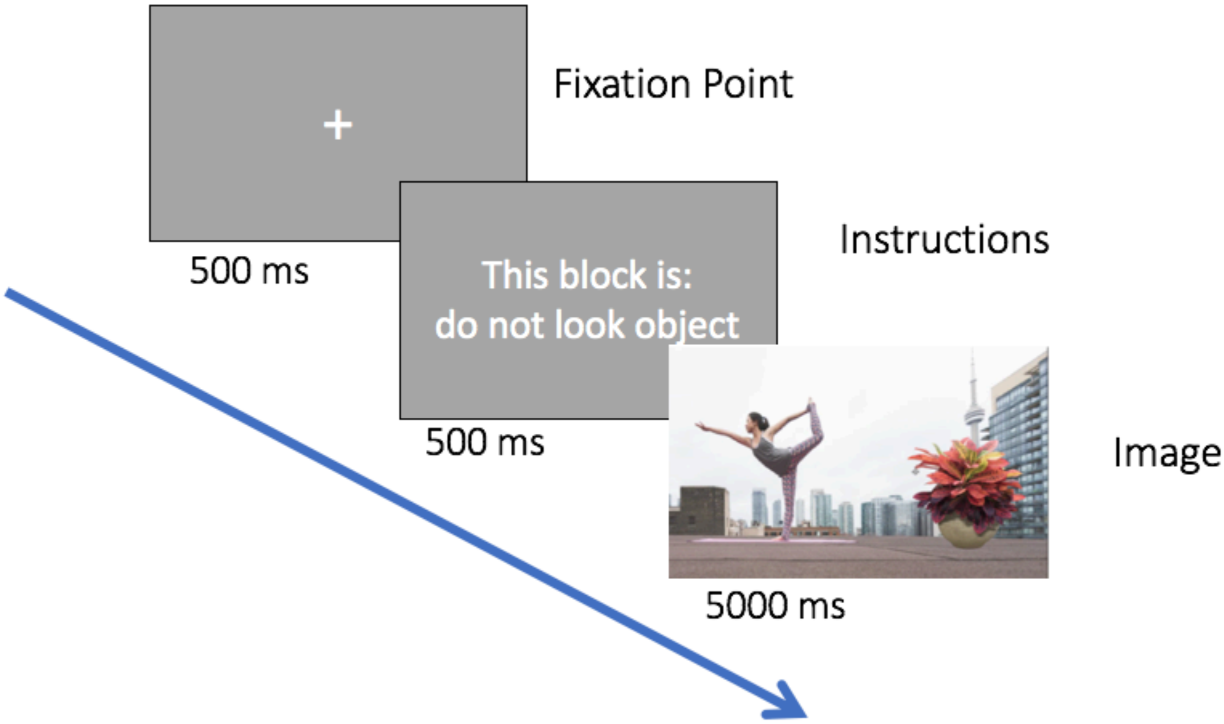


*Figure 17. Schematic representation of the stimuli and procedure of Experiment 6. This condition is a 'Do not look at the object' instruction. Here, the instructions are shown larger than in the actual experiment.*

Each trial started with a fixation cross displayed for 500ms, followed by the instructions for 500 ms. Participants were told that in each image, two elements will be shown: a social element (a person embedded) and an object, which would be presented in the opposite side of each other. At the beginning of each block the instructions were presented. For the DL social condition, participants were asked to avoid looking at an embedded person within the image. For the DL object condition, participants were asked to avoid looking at the object. In the third condition participants were asked to look freely. There were in total 27 scenes which were presented in 4 different combinations: flipped image (original, flipped) and object saliency (high or low) (a detail description of these images is described in chapter 2). The experiment contained 108 trials. All conditions were blocked and presented in a random order between participants. The total duration of the experiment was approximately 20 minutes.

**Design**: Two different designs were employed. The first, a two-factor design on the probability of fixating on the non-social object with different instructions (DL object, DL social and FV), and non-social object saliency (high and low). The second, a two-factor design on the probability of fixating on the social object with memory (high and low), and non-social object saliency (high and low).

## 6.6 Data Analysis and Results

Fixations were removed if their duration was below 100 ms. We also excluded trials where the starting fixation was not recorded on the centre. This resulted in the exclusion of four participants. We examined the effects of three different types of instructions: (1) do not look (DL) at the object area; (2) DL at the social area; (3) and Free viewing (FV) without any further instructions. As in the earlier experiments, we included a high and low saliency manipulation, and used questionnaires to investigate whether symptoms of ADHD and mind wandering are related to the distractibility in this task.

Figure 18 shows the percentage of all fixations on each region of interest (ROI). Participant means were entered into an ANOVA with the factors of instructions (DL object, DL social and FV) and ROI (social, non-social element). There was an effect of instructions $F(2,50) = 18.079$, $p<0.001$ $\eta^2 = 0.420$, indicating that there are more fixations in the DL object condition. There was an effect of ROI $F(1,25) = 77.590$ $p< 0.001$ 001 $\eta^2 = 0.756$, indicating that there are more fixations on the social area regardless of instructions. Most importantly, there was an interaction between instruction and object $F (2,50) = 226.398$ $p < 0.001$ $\eta^2 = 0.091$ indicating that the number of fixations vary between ROIs and conditions. In the DL social condition, there were more fixations on the non-social object than the social object, but this pattern was completely different in the DL object condition. In other words, the pattern matched the instructions.  Also, the FV pattern showed greater fixations to the social element than the non-social element, which is similar to the DL object. This analysis provides evidence that participants performed adequately in response to the instructions.

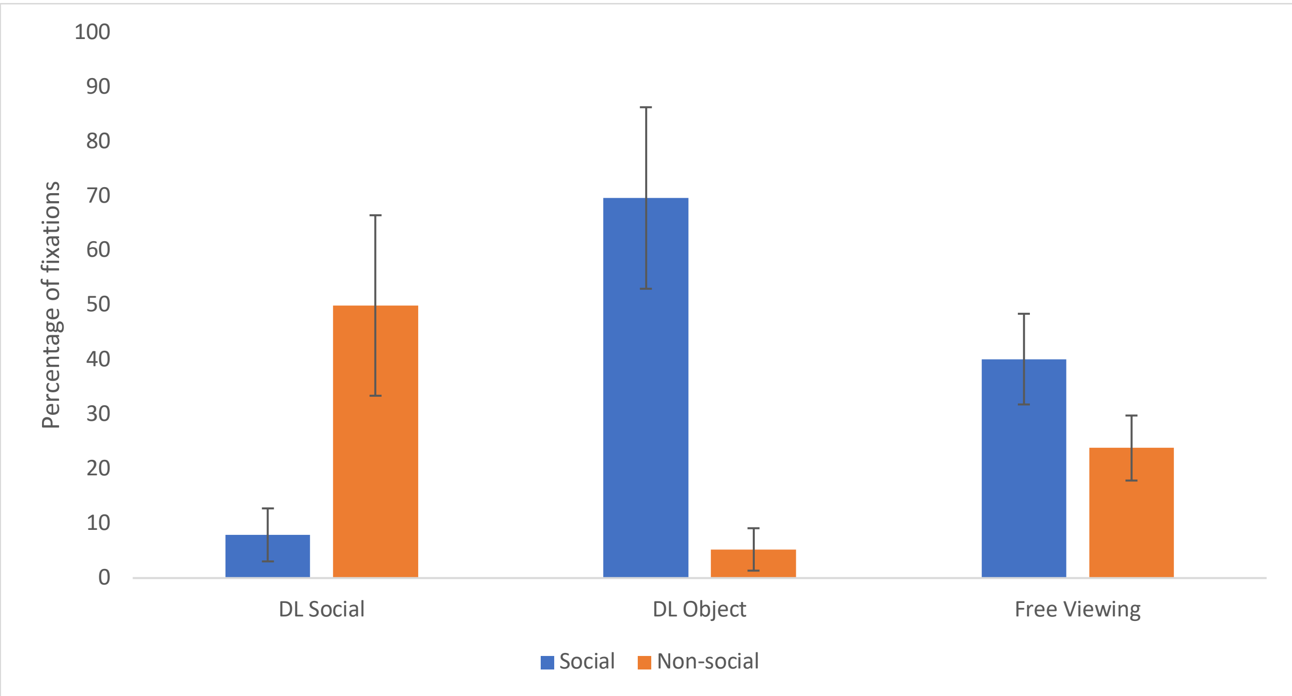


*Figure 18 Percentage of all fixations on the two ROI (social and non-social) as a function of instructions (DL Object, DL Social and FV). Errors in the bars represents SD.*

## *6.6.2 Early fixations*

Bottom-up and automatic processes are reported to operate earlier in time than top-down processes. As such, we compared performance during the second and third fixations. Second and third fixations on average lasted the first second of the trial, therefore we considered such fixations for the following analyses.

Recall that we predicted that if looking at the social area is a consequence of an automatic process, and this process is stronger than looking at the non-social area, then participants in the DL: social instructions would perform worse (i.e., make more errors by looking at the social area) than in the DL: object condition.  For completeness purposes, we analysed the early fixations using the same procedure as previously. We first entered participant means into a within-subject ANOVA (means and standard deviations are presented in table 13) with the factors of instructions (DL: object, DL: social, and free-viewing), and ROI (social and non-social). There was an effect of instructions $F (2,50) = 4.957$, $p = 0.011$, $\eta^2 = 0.165$, indicating more fixation on the DL object area. There was an effect of ROI $F (1, 25) = 63.933$ $p < 0.001$ $\eta^2 = 0.719$, indicating more fixations on the social area. There was an interaction between instruction and object $F (2, 50) = 91.678$ $p < 0.001$ $\eta^2 = 0.786$, indicating a variation between the different conditions and ROIs. This analysis too provides evidence of an adequate performance within the different instructions. However, this is not sufficient to draw conclusion on whether looking at the social element is a consequence of an automatic process. Therefore, we performed a paired sample t-test considering the percentage of fixations on the incorrect area. The social area in the DL: social condition had more fixations than the non-social area in the DL object condition, t (25) =-

2.419, p = .023. This analysis provides evidence of a bias towards the social area in the early viewing fixations.

| Instructions | Social | Non-social |
|---|---|---|
| DL Social | 16.048 (10.31) | 47.225 (15.44) |
| DL Object | 61.785(17.38) | 8.992(7.82) |
| FV | 44.978(15.23) | 15.987 (9.68) |

*Table 13 The percentage of fixations (means and standard deviations) per instructions as a function of social and non-social object. DL (Do not look at), FV (Free Viewing).*

The social and salient areas of an image are both reported to capture attention earlier in time and more so than non-social areas. Yet, previous research has not investigated the effects of these elements (social and non-social object) competing within a scene. Recall we expect that the high salient non-social element should facilitate attentional capture by avoiding a social element distraction. Consequently, the performance in the DL social should be worse (more errors) in the lower salient non-social element, but not in the higher salient non-social element.

To investigate this matter, we first performed a within-subject ANOVA (means and standard deviations are presented in table 14) with the factors of instructions (DL: object, DL: social, and free-viewing), saliency (high and low) and ROI (social and non-social). There was an effect of instructions F (2,50) = 3.885, p = 0.030, $\eta^2 = 0.135$, indicating that the DL object had more fixations than the other conditions. There was not an effect of saliency F (1, 25) = 0.289, p = 0.595 $\eta^2 = 0.011$, indicating that salient areas did not have more fixations that the non-salient areas. There was an effect of ROI, F (1,25) = 66.421 p < 0.001 $\eta^2 = 0.727$, indicating that the social area had more fixations than the non-social area. There was an interaction between instructions and saliency F (2, 50) = 5.391, p = 0.013 $\eta^2 = 0.177$, indicating that salience information (high and low) and instructions guided earlier fixations. There was an interaction between instructions and ROI $F(2, 50) = 94.245$, $p < 0.001$ $\eta^2 = 0.790$, indicating that the number of fixations vary between instructions and ROIs. There was not an effect of saliency and ROI interaction $F(1, 25) = 2.198$, $p = 0.151$ $\eta^2 = 0.081$. There was not an effect of instructions, saliency and ROI interaction $F(2, 50) = 2.421$, $p = 0.102$, $\eta^2 = 0.088$. Overall, this analysis confirmed a difference between performance in the different task instructions conditions, with very little role of saliency.

| | HS | | LS | |
|---|---|---|---|---|
| | Social | Non-Social | Social | Non-Social |
| DL Object | 69.75 (17.10) | 8.55 (11.30) | 53.36 (26.00) | 8.53 (11.10) |
| DL Social | 13.21 (13.30) | 45.43 (25.50) | 18.05(14.00) | 48.36(21.60) |
| FV | 45.06(15.5) | 15.43 (12.00) | 45.48 (18.10) | 17.01(13.90) |

*Table 14 The percentage of fixations (mean and standard deviations) per instructions as a function of social and non-social object and saliency (high and low), DL (Do not look at), FV (Free viewing).*

We then performed a within-subject ANOVA with the fixations on social ROI in DL social instruction and object ROI in DL object, as a function of saliency (high and low) and instructions (DL object and DL social). There was not an effect of saliency $F(1, 25) = 1.401$, $p = 0.248$ $\eta^2 = 0.053$. There was an effect of instructions $(1, 25) = 6.378$, $p = 0018$ $\eta^2 = 0.203$, indicating that there are more fixations on the DL object instruction than in the DL social. There was not an effect of saliency and ROI interaction $F(1, 25) = 0.785$, $p = 0.384$ $\eta^2 = 0.030$.

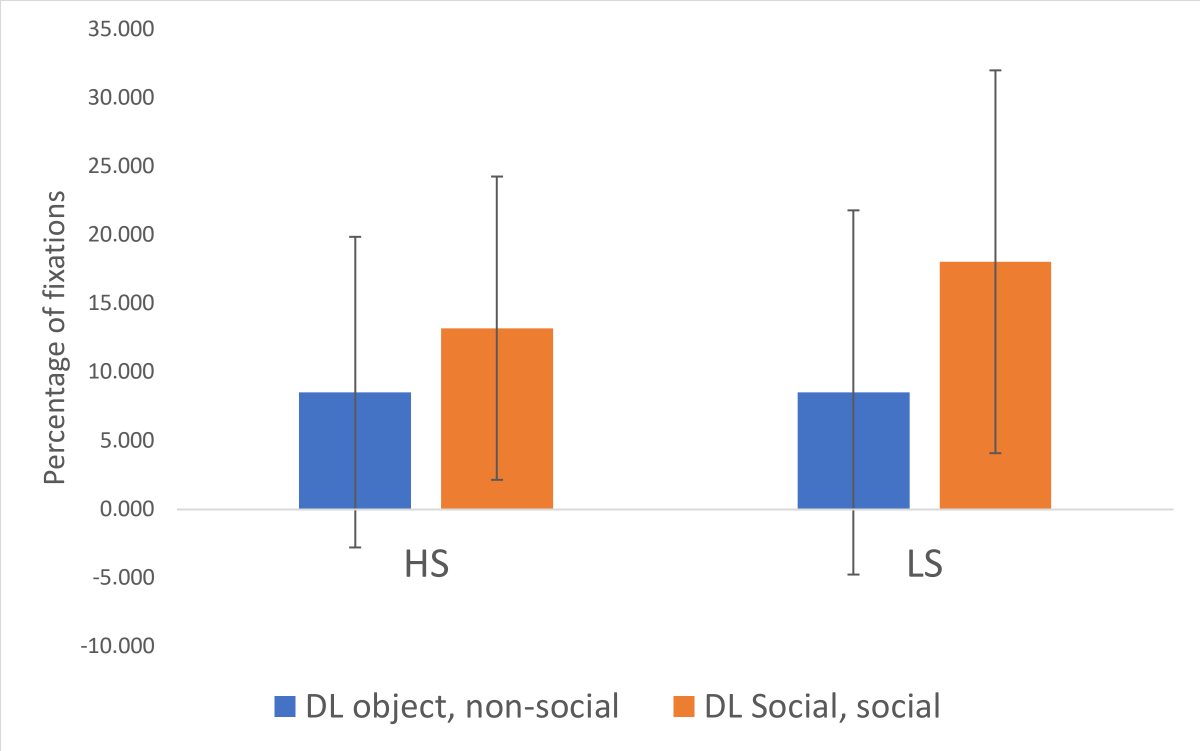


*Figure 19 Percentage of fixations on the two ROI (social and non-social) as a function of saliency (high and low). Errors in the bars represents SD.*

## *6.6.3 ADHD-like behaviour on image viewing*

ADHD is known to be a disorder with a difficulty to avoid irrelevant information (Barkley, 2011). Thus, it is possible that ADHD-like behaviour could be manifested as an aberrant eye movement behaviour. Participants with higher traits of ADHD should find it harder to follow instructions; they should perform with more errors in the restricted conditions over the free viewing condition. Furthermore, if social impairments are a characteristic behaviour in ADHD, then we expect that ADHD traits to be related to an avoidance behaviour (i.e., lesser fixations) to the social object, but not in the non-social object in a scene.

Scores on the ASRS checklist varied from 11 to 52 and the mean score was 29.46 (11.12). We correlated the total score of each participant from the ASRS questionnaire with the general dependent variables described previously. The correlation values are presented in Table 15. A weak relationship was found when correlating ADHD severity with probability of fixations on the non-social area in the free-viewing condition. The direction shows that participants with higher scores in the ASRS questionnaire fixate more to the non-social element when free viewing.

| Instructions | ADHD severity | Pearson R | p- value |
|---|---|---|---|
| DL Object | PF social | 0.107 | 0.602 |
| | PF non-social | 0.100 | 0.627 |
| DL Social | PF social | -0.122 | -0.553 |
| | PF non-social | 0.078 | 0.704 |
| FV | PF social | 0.036 | 0.863 |
| | PF non-social | **0.397** | **0.045** |

*Table 15 Correlation values for ADHD severity and the fixation variables. PF = Percentage of fixations, N=26.*

### *6.6.4 Mind-wandering behaviour on image viewing*

ADHD is commonly associated with mind-wandering behaviour. Therefore, we expected to have a similar eye movement behaviour. As previously, we correlated the total score of each participant from the MEWS questionnaire with the general dependent variables. Scores on the MEWS checklist varied from 0 to 24 and the mean score was 12.00 (6.48). The scores from MEWS and ASRS had a strong and positive relationship between the symptoms $r = .784$, $n= 26$, $p< 0.001$. We also found a moderate relationship between non-social element and the mind-wandering severity symptoms (the correlation values are presented in Table 16.). The directions indicate that participants with higher scores in the MEWS fixated more to non-social areas in the free-viewing condition.

| Instructions | Mind-wandering symptoms | Pearson R | p- value |
|---|---|---|---|
| DL Object | PF social | 0.078 | 0.706 |
| | PF non-social | 0.276 | 0.173 |
| DL Social | PF social | -0.160 | 0.435 |
| | PF non-social | 0.097 | 0.636 |
| FV | PF social | -0.094 | 0.649 |
| | PF non-social | **0.482** | **0.013** |

*Table 16 Correlation values for Mind Wandering symptomatology and the fixation variables. PF = Percentage of fixations, N=26.*

## 6.7 Discussion

A line of experiments in this thesis has shown a strong bias to social areas in a scene. The current study used an image-viewing task to examine visual attention featuring social and non-social objects. Using restricted 'do not look, DL' instructions, this study reports the percentage of looks at the social and non-social areas and the percentage of looks at the non-social object with high and low salience information. Furthermore, this study reports task performance related to individual differences in Mind-wandering and ADHD. The study reviewed leads to predictions that: (1) performance in the DL social should lead to more errors (greater percentage of fixations) in social areas over non-social areas as a consequence of an automatic process. (2) increased salience should facilitate attentional capture by avoiding a social element distraction, (3) increased ADHD and MW symptoms should be related to more errors in the restricted conditions due to difficulty following instructions, (4) if social impairments are a characteristic behaviour in ADHD, then increased ADHD traits should lead to lesser fixations to the social object (vs non-social object), (5) increased MW should lead to increasing ADHD: showing a similar behaviour response across instructions.

There are some interesting findings in this study. First, the study reports greater percentage of fixations (as more errors) in social areas over non-social areas in their restricted counterparts in line with previous studies in social attention that suggested a bias to social areas (Birmingham et al., 2009; End & Gamer, 2019; Flechsenhar et al., 2018; Freeth et al., 2013; Laidlaw et al., 2011). Contrary to End and Gamer's (2019) study in which participants were asked to look directly to the social elements and consider the salience information too, we asked participants to avoid looking at the social element. In Laidlaw et al's (2011) study, they used a face as stimuli, in this chapter the stimuli were a social (a person) and a non-social object with high and low salience information. This is the first study that uses the 'do not look' paradigm to investigate attentional capture with social and salience information.

Second, this bias is also observable in early viewing fixation (in the first second after image presentation) as reported by Crouzet, (2010). In Laidlaw et al (2011), they found more fixations early on time than later on time, however, this study shows a strong bias towards the social element early on time and in the total number of fixations. Contrary, to the salience effect which has been reported to be present only early on time (Theeuwes, 2018), this process seems to be automatic such as you cannot stop looking at this social area over the time.

Third, the higher or lower salience properties of the scene does not seem to affect this social prioritisation. This finding can be explained that task demands override the salience effect in the non-social object as previously reported (Foulsham & Underwood, 2008, 2009). Fourth, symptoms of ADHD and MW were positively associated with greater number of fixations in the non-social object regardless of their salience in the Free-viewing condition. It seems that in this condition participants were using less cognitive resources and therefore, were more prone to look at the non-social object areas as reported previously (Forster et al., 2014; Forster & Lavie, 2016). It is also plausible that the Free-viewing condition is more sensitive to detect individual differences in attentional impairments. Lastly, it was not surprising to find the MEWS and ASRS correlated, since MW is part of the symptomatology of ADHD. Therefore, the same behavioural response for the MW and ADHD were found across the task.

In conclusion, this study examines the effects of instructions on an image-viewing task. Also, it reports the relationship between task performance and attentional impairments. The results show that it is harder to avoid looking at social elements (as reported with a greater number of errors) than looking at non-social elements. Interestingly, the non-social element with higher salience does not facilitate avoiding looking to the social area in the restricted conditions. The salience information does not affect overall the social prioritisation. The relationship between attentional impairments and task performance was found in the percentage of fixations to the non-social object in the FV condition. This relationship was detected in ADHD and MW symptoms, as an indication of increased ADHD and MW symptoms increased looks at the non-social object.

# Supplementary Data Analysis:
# The leftward bias in image viewing

When images are presented in lab settings, participants tend to direct their second fixation to the left side of the screen (Foulsham, Gray, et al., 2013; Foulsham et al., 2018; Foulsham & Kingstone, 2010; Guo et al., 2009; Dickinson & Intraub, 2009; Dundas et al., 2013). This phenomenon has been observed in scenes (Foulsham et al., 2018), faces (Guo et al., 2009) and words (Dundas et al., 2013).

Guo et al (2009) used faces to assess human adults, human infants, rhesus monkeys and domestic dogs in a preferential looking paradigm. Results showed that 6-month-old infants have a left prioritisation towards objects and faces of different species and orientations. In adults, the left bias was only observable in upright human faces. In Rhesus monkeys, the left bias was observed in upright humans and monkey faces, but not in inverted faces. In domestic dogs, the left bias was observed in human faces only. Their results showed that the left bias is observed at different extent within species. Developmentally, the study from Dundas et al (2013) provides evidence of this left prioritisation develops at different ages and make a distinction between faces and words.

In this supplementary section, I combined the data from experiments 3, 4, 5 and 6. Then, I examined whether the left bias effect is a memory load-dependent (in experiments 3,4 and 5) or instructions-dependent (in experiment 6).

In the first analysis, I consider the data collected from experiments 3 to 6. Then, I analysed whether the second fixation was more likely than chance to be located in the left side of the image area in a one sample t-test against 0.5, t (112) = 21.663, $p < 0.001$. The analysis indicates the 49.45% (SD = 24.02) of the second fixations tend to be on the left side of the images. Figure 20 shows all the second fixations from this left-bias analysis.

*Figure 20. Schematic representation of the second fixations from one example image in Experiment 3.*

In the second analysis, I consider the data collected from experiments 3, 4 and 5 only, since, in these experiments two different loads were manipulated. I ran a paired sample t-test with the high 53.98 (SD = 25.80) and low 51.35 (18.95) condition in the probability of fixating to the left side of the image considering the second fixation $t(86) = .929$, $p = 0.356$. Figure 21 shows data from experiments 3, 4 and 5 considering only the second fixation.

*Figure 21 Schematic representation of the second fixations from Experiment 4 and 5.*

In the last analysis. I consider the probability of fixating on the left side of the image from Experiment 6 and analysed whether the second fixation was more likely than chance to be located in the left side of the image area in a one sample t-test against 0.5, $t(25) = 2.266$, $p = 0.032$. By splitting the data into conditions, DL social = 54.98 (22.64), DL non-social = 54.22 (18.31), and free viewing 60.89 (20.58), it is evident that there are left bias remain regardless of restricted instructions. Figure 22 shows data from experiment 6 considering only the second fixation.

*Figure 22 Schematic representation of the second fixations from Experiment 6*

# Chapter 7
# The effect of individual differences in ADHD-like behaviour on eye gaze in conversation videos

**Abstract**

The present chapter investigates the effect of occluding the eyes when observing a pre-recorded natural conversation. We aimed to understand how populations with high and low traits of ASD (Experiment 7) and ADHD (Experiment 8) utilise the eyes as a social cue. Results show that the social object was fixated to a greater degree than the other areas of the videoclips. Furthermore, auditory information, eyes occlusion and the subclinical samples affect to some degree the prioritisation in some areas (eyes and mouth) of the videoclips. Such findings suggest that occluding the eyes in social conversation in dynamic stimuli can counteract the avoidance of attending to the eyes and mouth areas.

## 7.1 Introduction

Gaze following plays an important role in the communication and interaction in conversation (Tomasello, 2008). In social attention research, it has been shown a strong prioritization to the face area (Foulsham et al., 2010; Foulsham & Sanderson, 2013; Vo et al., 2012). This face prioritisation is particularly strong in conversation. For instance, Foulsham and Sanderson, (2013) examined whether who is talking and who is being fixated depends on having or not auditory information. The authors presented participants with videos showing four individuals in a conversation. Half of the videos were with sound-on and the other half with sound-off. In the sound-on condition, they found that individuals who talked the most were likely to have more looks than those who did not talk that much. Contrary, in the sound-off condition, participants who talked less were likely to have more looks than those who did talk (as these individuals were not moving their mouths that much). The research reviewed so far in this thesis highlights several influences on visual attention on social elements: the face area and the presence of auditory information has an effect on where we look (Birmingham et al., 2009; End & Gamer, 2019; Flechsenhar et al., 2018; Foulsham & Sanderson, 2013; Freeth et al., 2013; Laidlaw et al., 2011; Vo et al., 2012). The present study aimed to evaluate the effect of auditory information in social attention during conversation. Unlike previous research on conversation (Foulsham et al., 2010; Foulsham & Sanderson, 2013), we designed clips in which individuals had the eyes occluded by wearing sunglasses in half of the trials, and in the other not.

Eye aversion is one of the key characteristics  of Autism Spectrum Disorder (ASD) causing impaired social interaction and communication (American Psychiatric Association, 2013). A considerable body of research has investigated the extent to which people diagnosed with ASD show different eye movements patterns of prioritisation in social contexts (i.e., Chita-Tegmark, 2016a, 2016a; Seernani et al., n.d.; Tye et al., 2013). Although there is a consensus that ASD vs non-ASD participants show less gaze fixation on the eyes' areas (Chita-Tegmark, 2016a, 2016a), there are mixed findings  on where they choose to address their attention (i.e., other body parts or an object). For instance, Scheerer et al., (2021) used an attentional capture paradigm to examine whether ASD vs non-ASD individuals have a stronger prioritisation towards trains over faces. Participants were asked to indicate whether a butterfly target was present or absent using a keyboard response. In half of the trials, a face was presented, while in the other half a train. Although they did not find any attentional capture effect on the type of stimuli (trains vs faces), they found slower reaction times on present vs absent targets in the ASD vs non-ASD group. Klin et al., (2002), found differences in object vs area gaze fixation duration. The authors assessed the level of social adjustment and social impairment in ASD vs non-ASD participants by using video clips with social content and recording participants' eye movements. In the analysis, there were four regions of interest: eyes, mouth, body and objects. Results indicated that higher scores in social adaptation were related to greater time spent in the mouth area. Higher scores in social disability were related to lesser time spent in the object area. Bast et al., (2020) used a mobile eye tracker to investigate and compare the viewing behaviour of ASD vs non-ASD individuals. Participants watched naturalistic videos, half of the videos including a social content (i.e., a person). They found that participants with ASD had smaller saccade durations and amplitudes compared to the control group regardless of the video content. Furthermore, Freeth et al., (2013) demonstrated that in a community sample those with greater symptoms of ASD looked less to people when watching videos. However, there was no difference in the live situation. They examined the proportion of time spent viewing a confederate face to face or via video and correlated their viewing behaviour with symptoms of ASD. They proposed that the increased attention to faces when viewing videos in a population low on ASD symptoms is because another person's face and gaze are extremely captivating. These findings corroborate previous results that ASD symptoms are characterised by abnormal viewing behaviour and suggest that the stimulus presentation facilitates this social avoidance. In the present study, we aimed to explore this further by testing stimuli of a group conversation in a community sample with traits of ASD.

One consideration in the study of ASD is the high estimated prevalence rate of comorbid psychiatric disorders (Antshel et al., 2016; Dobrosavljevic et al., 2020; Hansen et al., 2018; Jang et al., 2013). One of the disorders identified with a strong connection to ASD is ADHD (American Psychiatric Association, 2013; Antshel et al., 2016; Hansen et al., 2018). Some of the cognitive deficits and symptoms of ADHD overlap with those seen in ASD (Antshel et al., 2016; Jang et al., 2013; Seernani et al., 2021). Seernani et al., (2021) examined the eye movements of ADHD, ASD, ASD+ADHD, and a control group in a visual search study. They found that the ASD group had better performance in the visual search task compared to the others. The ASD+ADHD participants were slower, inefficient, and had longer fixations. However, there was no evidence for better or worse performance in the ADHD individuals. The authors suggested that the comorbid group should be seen like a separate group with its own symptoms and impairments, rather than as an addition of the ASD and ADHD groups. In this chapter, we examined the symptoms of ASD and ADHD as separate groups within a community sample.

Some of the research on ADHD investigating social attention functioning has implemented static stimuli (i.e., pictures).  Much of this endeavour has been to understand emotion identification (e.g., Tye et al., 2013) or gaze cueing (Marotta et al., 2014; Raz & Dan, 2015). Marotta et al., (2014) implemented a paradigm with three different conditions (eye gaze, arrows, and peripheral onset cues) in an ADHD vs non-ADHD group. Participants were asked to respond either to the left or the right depending on the condition, and either congruently or incongruently depending on the target presentation by pressing a keyboard response. They did not find any differences in the arrow and the peripheral onset cues conditions. However, participants without ADHD performed quicker in the gaze following congruent condition relative to the incongruent, whereas participants with ADHD showed no such effect. Furthermore, Serrano et al., (2018) examined and compared the eye movement behaviour in an ADHD vs non-ADHD group by using images with seven different facial expressions and scenes with a social content expressing an emotion. They found that participants with ADHD spent less time looking at the social area and specific areas, such as the eyes and mouth relative to the control group. Also, the ADHD group showed slower reaction times compared to the control group. Taken together, these findings suggest that ADHD participants demonstrate an abnormal eye movement behaviour when viewing social stimuli compared to participants without ADHD. Furthermore, we have previously reviewed that impairments in eye movement behaviour are also observable in people with high traits relative to those with low traits of ADHD (Crosbie et al., 2013; Jang et al., 2020; Panagiotidi et al., 2017).

## 7.2 The current chapter

The present study investigates the effect of occluding the eyes when observing a pre-recorded natural conversation. By considering these aspects, we further aimed to understand how populations with high and low traits of ASD (Experiment 7) and ADHD (Experiment 8) utilise the eyes as a social cue. This chapter uses a similar methodology to Foulsham and Sanderson, (2013) study, whereby participants will watch stimuli of video clips depicting target individuals sat at a table engaging in a group discussion. This methodology comprises of third-party participants watching group conversations which have previously been recorded, with clips prepared for a static eye-tracker. In half of the clips individuals in the scene (targets) will be wearing sunglasses to occlude their eyes (Sunglasses condition) and in the remainder their eyes will be visible (Control condition). We have three main objectives.

First, we explore how occluding the eyes affects fixations to individuals within the scene. We investigate to what extent overall looking to people and their facial features (eyes and mouths) are affected by sunglasses occluding their eyes. Previous research has reliably found that we tend to look at social aspects of the scene (Flechsenhar et al., 2018) and in particular the eyes (Laidlaw & Kingstone, 2017). For this reason, we expect the low traits group in ASD and ADHD participants to reliably look to the target individuals within the scene and to the eyes when they are visible. When occluding the eyes with sunglasses, we may expect a decrease in looks to the eyes, as there is no additional benefit (i.e., no understanding of intentions or signalling) to be gained by fixating this area. Equally, we may see no difference due to habit or even an increase in attention as this is a novel item within the scene. Second, we assess how and when a speaker is observed when occluding the eyes with a comparison of the Control and Sunglasses conditions. We test the effect of using the eyes as a signalling cue. We will explore whether wearing sunglasses impedes the observer's ability to follow turn-taking information. This will be investigated in terms of percentage of looking behaviour to those currently speaking.

## 7.3 Experiment 7

Experiment 7 examines eye movements in participants with ASD-HT and ASD-LT whilst watching conversation videos. Furthermore, it examines whether auditory information (these targets who are currently speaking) and eyes' occlusion affect social attention.

## 7.4 Methods

## 7.5 Participants

We collected eye-movement data from 41 Individuals.

## 7.6 Apparatus

The apparatus is described in chapter 2.

## 7.7 ASD symptoms and classification

Pre-screening classification is described in chapter 2

**Design**: Two-factor design within different conditions (Sunglasses or Control), and between-subjects (high and low) on the probability of fixating to targets, of fixating to targets eyes' and mouth, and targets speaking.

# 7.8 Data analysis and Results on ASD

## *7.8.2 General eye movement behaviour*

First, we examined how participants with ASD-HT and ASD-LT responded to the conversation clips by analysing general eye movements as presented in Table 17.

*Table 17 Total Number of Fixations, Number of fixations per clip, and Fixation Duration (in milliseconds) averaged for each group ASD-HT (High traits) and ASD-LT (Low traits).*

| | Total Number of Fixations | Mean Fixations Per Clip | Mean Fixation Duration (ms) |
|---|---|---|---|
| ASD-HT | 614.57 | 76.82 | 388.43 |
| *SD* | *100.05* | *12.51* | *83.19* |
| ASD-LT | 675.45 | 84.43 | 361.10 |
| *SD* | *130.46* | *16.31* | *97.35* |

We ran two independent sample t-tests on average number of fixations, ($t$ (39) = 1.689, $p$ =.10), and average fixation duration ($t$ (39) =-0.96, $p$ =.33). These both revealed non-significant differences between the two groups, indicating that participants' general viewing behaviour were similar.

### *7.8.3 Eye movements to targets*

We then considered the number of fixations to the ROI (The ROI are described in chapter 2). Participants average percentage of fixations to the ROI's were entered into an ANOVA (means and standard deviations are presented in Table 18) with the within-subjects factor of Condition (Sunglasses or Control) and the between-subjects factor of Group (ASD-HT or ASD-LT). There was no effect of condition $F(1, 39) = 2.192$, $p = 0.147$ $\eta^2 = 0.053$, or group $F(1, 39) = 0.070$, $p = 0.793$ $\eta^2 = 0.002$ and no interaction between condition and group $F(1, 39) = 0.638$, $p = 0.429$ $\eta^2 = 0.016$. This suggests that both groups and conditions behave similarly when analysing overall looks to targets.

| | | Mean % Fixations to Targets | | | |
|---|---|---|---|---|---|
| | | Control | | Sunglasses | |
| | | Targets | Elsewhere | Targets | Elsewhere |
| ASD-HT | M | 97.83 | 2.17 | 98.04 | 1.96 |
| | *SD* | *1.71* | *1.71* | *3.07* | *3.07* |
| ASD-LT | M | 97.73 | 2.27 | 98.45 | 1.55 |
| | *SD* | *1.42* | *1.42* | *1.95* | *1.95* |

*Table 18 Represents the average percentage of fixations to targets, split by condition and group.*

### *7.8.4 Fixations to Targets' Eyes and Mouth*

Previous studies have found a tendency to fixate the eyes in a general population in both images and video (e.g., Birmingham, Bischof and Kingstone, 2007). For this reason, we investigated whether there was an effect of Condition and Group on looks to specific regions of the face. Fixations on targets were then analysed to determine where they were inside the total target area.

Participants' average probability of fixations to the ROIs were entered into a mixed ANOVA (means and standard deviations are presented in Table 19) with the within subject factors of condition (Sunglasses and Control), area (mouth and eyes) and the between subjects' factor depending on group (ASD-HT or ASD-LT). There was an effect of area $F$ (1, 39) =17.516, $p < .001$, $\eta^2 = .096$, indicating that participants fixated more to the eye area compared to the mouth area. There was an effect of group $F$ (1, 39) =6.266, $p = .017$ $\eta^2 = .138$, indicating that the ASD -LT group made more fixations to both areas (eyes and mouth) in comparison to the ASD -HT group. There was also an effect of condition, $F$ (1, 39) =122.389, $p < .001$, $\eta^2 = .758$. Interestingly, this was qualified by an interaction between condition and area $F$ (1, 39) =29.804, $p < .001$, $\eta^2 = .433$, indicating that the bias to look at the eyes rather than the mouth was more pronounced in the Sunglasses condition compared to the Control condition.

| | | Mean % Fixations to Targets | | | | | |
|---|---|---|---|---|---|---|---|
| | | Control Condition | | | Sunglasses Condition | | |
| | | Eyes | Mouth | Elsewhere | Eyes | Mouth | Elsewhere |
| ASD-HT | M | 25.27 | 14.29 | 60.44 | 41.47 | 15.94 | 42.59 |
| | *SD* | *15.77* | *13.42* | *13.05* | *21.77* | *11.72* | *19.48* |
| ASD-LT | M | 32.24 | 17.38 | 50.37 | 45.59 | 23.17 | 31.24 |
| | *SD* | *15.25* | *14.08* | *8.08* | *20.00* | *15.46* | *15.58* |

*Table 19 The mean percentage of fixations to targets' eyes and mouth, split by Group (low and high traits of ASD) and Conditions (control and sunglasses. Fixations outside the main target ROIs are not included here.*

## 7.8.5 Fixations to speakers

| | | Mean % Fixations to Speaking Targets | | | |
|---|---|---|---|---|---|
| | | Control Condition | | Sunglasses Condition | |
| | | Targets | Elsewhere | Targets | Elsewhere |
| ASD-HT | M | 45.33 | 54.67 | 53.19 | 46.81 |
| | *SD* | *6.49* | *6.49* | *4.27* | *4.27* |
| ASD-LT | M | 48.21 | 51.79 | 54.91 | 45.09 |
| | SD | *4.86* | *4.86* | *3.98* | *3.98* |

*Table 20 Represents the average percentage of fixations to targets on speaking targets split by Condition and Group. The elsewhere category includes fixations on the other non-speaking targets and any non-target fixations.*

We were then interested in analysing looks to targets who are currently speaking. Participants' average probability of fixations on the speaking targets was entered into a mixed ANOVA (means and standard deviations are presented in Table 20) with the within subjects' factors of Condition (Sunglasses and Control), and between-subjects factor of group (ASD-HT or ASD-LT). There was an effect of condition $F\ (1, 39) = 139.010$, $p < .001$, $\eta^2 = .781$, indicating that participants made more fixations to speaking targets in the Sunglasses condition than in the Control condition. There was no effect of group $F\ (1, 39) = 2.493$, $p = 0.122$ $\eta^2 = 0.060$, and no interaction between condition and group $F\ (1, 39) = 0.531$ $p = 0.470$ $\eta^2 = 0.013$.

### *7.8.6 Fixations to speakers' eyes and mouth*

The probability of fixations to targets eye and mouth regions were then analysed in terms of whether the target was currently speaking or not. The average percentage of fixations to targets eyes and mouths and elsewhere (of those fixations which are on the target) when they are currently speaking can be seen in Table 21.

| | | Mean % Fixations to Targets | | | | | |
|---|---|---|---|---|---|---|---|
| | | Control | | | Sunglasses | | |
| | | Eyes | Mouth | Elsewhere | Eyes | Mouth | Elsewhere |
| ASD-HT | M | 13.18 | 7.91 | 78.91 | 22.36 | 8.19 | 69.45 |
| | *SD* | *9.93* | *7.90* | *8.80* | *12.75* | *6.05* | *11.96* |
| ASD-LT | M | 17.97 | 10.26 | 71.77 | 25.99 | 10.98 | 63.03 |
| | *SD* | *9.30* | *8.32* | *5.84* | *12.30* | *7.79* | *9.70* |

*Table 21 Represents the average percentage of fixations to targets eyes and mouth and elsewhere on the target, whilst the target is currently speaking, split by Group (low and high traits of ADHD) and Condition.*

Participants' average probability of fixations to the ROI whilst the target was speaking were entered into an ANOVA (means and standard deviations are presented in Table 21) with the within subjects' factor of Condition (Sunglasses and Control), and between subjects depending on the Group ASD-HT or ASD-LT. There was an effect of condition $F$ (1, 39) = 70.692, $p < .001$, $\eta^2 = .644$, indicating that participants fixate more on both regions in the Sunglasses condition over the Control condition when the target is speaking. There was no interaction between condition and group F (1, 39) = 0.110, p = 0.741 $\eta^2 = 0.003$. There was an effect of area $F$ (1, 39) = 17.441, $p < .001$, $\eta^2 = .309$, indicating that participants fixate more to the eyes over the mouth when the target is speaking. There was no interaction between area and group F (1, 39) = 0.106, p = 0.747 $\eta^2 = 0.003$. There was an effect of group $F$ (1, 39) = 6.212, $p$ = .017, $\eta^2$ = .137, indicating that ASD-LT fixate more in both areas (eyes and mouth) over the ASD-HT when the target is speaking. There was an interaction between area and condition $F$ (1, 39) = 44.158, $p$ < .001, $\eta^2$ = .531, indicating that participants look more to the eyes in the Sunglasses condition when the target was speaking. There was interaction between condition x area x group F (1, 39) = 0.439, p = 0.511 $\eta^2$ = 0.011.

## 7.9 Experiment 8

Experiment 8 examines eye movements in participants with ADHD-HT and ADHD-LT whilst watching conversation videos. As in the previous section, this section also examines whether auditory information (these targets who are currently speaking) and eyes' occlusion affect social attention.

## 7.10 Participants

After pre-screening 248 students, we collected eye movement data only from 40 individuals

## 7.11 Apparatus

The apparatus is described in chapter 2.

## 7.12 ADHD symptoms and classification

Pre-screening classification is described in chapter 2.

**Design**: Two-factor design within different conditions (Sunglasses or Control), and between-subjects (high and low) on the probability of fixating to targets, of fixating to targets eyes' and mouth, and targets speaking.

## 7.13 Data analysis and Results on ADHD

### *7.13.2 General eye movement behaviour*

First, we examined how participants with ADHD-HT and ADHD-LT responded to the conversation clips by analysing general eye movements as presented in Table 22. We included this analysis to understand whether clips were overall visually attended to differently between groups.

| | Total Number of Fixations | Mean Fixations Per Clip | Mean Fixation Duration (ms) |
|---|---|---|---|
| ADHD-HT | 625.21 | 78.15 | 390.40 |
| *SD* | *106.19* | *13.27* | *65.11* |
| ADHD-LT | 628.15 | 78.52 | 397.83 |
| *SD* | *89.32* | *11.16* | *57.22* |

*Table 22 Total Number of Fixations, number of fixations per clip and fixation duration (in milliseconds) averaged for each group ADHD-HT (High traits) and ADHD-LT (low traits).*

We ran two independent sample t-tests on mean number of fixations, (*t* (37) =-0.09, *p* =.92), as well as on mean fixation duration (*t* (37) =-0.37, *p* =.70). These both revealed non-significant differences between the two groups, indicating that participants' general viewing behaviour was similar. The statistics here are also very similar to behaviour in the previous Experiment.

### *7.13.3 Eye movements to targets*

Participants' average percentage of fixations to the ROI's were entered into a mixed ANOVA (means and standard deviations are presented in Table 23) with the within-subjects factor of condition (Sunglasses and Control), and the between-subjects factor of group (ADHD-HT or ADHD-LT). There was no effect of condition $F(1, 37) = 0.107$, $p = 0.746$ $\eta^2 = 0.003$, or group $F(1, 37) = 2.290$, $p = 0.139$ $\eta^2 = 0.058$. Also, there was no interaction between condition and group $F(1, 37) = 1.722$, $p = 0.197$ $\eta^2 = 0.044$. These results show that both groups behave similarly when looking at the targets with and without sunglasses.

| | | Mean % Fixations | | | |
|---|---|---|---|---|---|
| | | Control | Elsewhere | Sunglasses | Elsewhere |
| ADHD-HT | M | 97.28 | 2.72 | 98.69 | 0.68 |
| | *SD* | *2.68* | *2.68* | *1.43* | *0.75* |
| ADHD-LT | M | 98.01 | 1.99 | 98.69 | 0.68 |
| | *SD* | *2.07* | *2.07* | *1.43* | *0.75* |

*Table 23 Represents the average percentage of fixations to targets, split by condition and group.*

## *7.13.4 Fixations to Targets' Eyes and Mouth*

Table 24 shows the average percentage of fixations to targets eyes and mouth and elsewhere on the target throughout the clips.

| | | Mean % Fixations to Targets | | | | | |
|---|---|---|---|---|---|---|---|
| | | Control | | | Sunglasses | | |
| | | Eyes | Mouth | Elsewhere | Eyes | Mouth | Elsewhere |
| ADHD-HT | M | 25.45 | 16.03 | 58.52 | 26.21 | 16.49 | 57.30 |
| | *SD* | *18.28* | *15.48* | *16.15* | *18.16* | *14.77* | *16.69* |
| ADHD-LT | M | 24.62 | 21.01 | 54.38 | 26.05 | 19.89 | 54.06 |
| | *SD* | *17.39* | *14.39* | *18.32* | *16.77* | *14.12* | *18.53* |

*Table 24 Represents the percentage of fixations to targets eyes, mouth and elsewhere on the target, split by Group and Condition.*

Participants' average probability of fixations were entered into a mixed ANOVA (means and standard deviations are presented in Table 24) with within subject factors of condition (Sunglasses and Control), ROI (eyes and mouth) and between subjects depending on the group (ADHD-HT or ADHD-LT). There was no effect of condition $F (1, 37) = 0.331$, $p = 0.569$ $\eta^2 = 0.009$. There was no interaction between condition and group $F (1, 37) = 0.116$, $p = 0.736$ $\eta^2 = 0.003$. There was no effect of area $F (1, 37) = 2.818$, $p = 0.102$ $\eta^2 = 0.071$. There was no interaction between area and group $F (1, 37) = 0.285$ $p = 0.590$ $\eta^2 = 0.008$. There was no interaction between condition and area $F (1, 37) = 0.752$, $p = 0.392$ $\eta^2 = 0.020$. There was no interaction between condition x area x group $F (1, 37) = 0.469$ $p = 0.498$ $\eta^2 = 0.013$. This pattern was slightly different from Experiment 1, where the addition of sunglasses led to more looks at the face.

### *7.13.5 Fixations to Speakers*

Participants average probability of fixations to the speaking targets was entered into a mixed ANOVA (means and standard deviations are presented in Table 25) with the within subjects' factors of Condition (Sunglasses and Control), and between-subjects factor of group (ADHD-HT or ADHD-LT). There was an effect of condition $F$ (1, 37) = 41.378 p = 0.001 $\eta^2$ = 0.528. There was no effect of group F (1, 37) = 0.767, p = 0.387 $\eta^2$ = 0.020. There was no interaction between condition and group F (1, 37) = 0.047, p = 0.830 $\eta^2$ = 0.001. Thus, demonstrating participants looked more to speakers in the sunglasses condition regardless of their group. This replicates the pattern observed in the previous Experiment.

| | | Mean % Fixations to Speaking Targets | | | |
|---|---|---|---|---|---|
| | | Control | | Sunglasses | |
| | | Targets | Elsewhere | Targets | Elsewhere |
| ADHD-HT | M | 45.59 | 54.41 | 51.65 | 45.11 |
| | SD | 5.85 | 5.85 | 6.56 | 6.35 |
| ADHD-LT | M | 46.77 | 53.23 | 53.24 | 49.57 |
| | SD | 4.70 | 4.70 | 5.97 | 5.11 |

*Table 25 Represents the average percentage of fixations to targets, split by Condition and Group.*

### *7.13.6 Fixations to Speakers eyes and mouth*

The probability of fixations to targets eye and mouth regions were then analysed in terms of whether the target was currently speaking or not. The average percentage of fixations to targets eyes and mouths and elsewhere (of those fixations which are on the target) when they are currently speaking can be seen in Table 26.

| | | Mean % Fixations to Targets | | | | | |
|---|---|---|---|---|---|---|---|
| | | Control | | | Sunglasses | | |
| | | Eyes | Mouth | Elsewhere | Eyes | Mouth | Elsewhere |
| ADHD-HT | M | 12.11 | 8.48 | 79.41 | 14.63 | 10.01 | 75.36 |
| | *SD* | *9.30* | *8.34* | *8.73* | *10.83* | *8.99* | *10.23* |
| ADHD-LT | M | 12.07 | 10.87 | 77.06 | 14.48 | 11.52 | 74.00 |
| | *SD* | *9.25* | *8.46* | *10.81* | *10.65* | *8.80* | *11.44* |

*Table 26 Represents the average percentage of fixations to targets eyes, mouth and elsewhere on the target, whilst the target is currently spealing, split by group (low and high traits of ADHD) and condition.*

As before, participants' average percentage of fixations whilst the target was speaking were entered into an ANOVA with the within subject factors of Condition (Sunglasses and Control), ROI (eyes and mouth) and between subjects depending on the Group ADHD-HT or ADHD-LT. There was an effect of the condition $F$ (1, 37) =15.393, $p$ = .001, $\eta^2$ = .294), indicating that there were more fixations in the Sunglasses condition than in the Control condition regardless of the group. There was no interaction between condition and group F (1, 37) = 0.298, p = 0.588 $\eta^2 = 0.008$. There was no effect of area F (1, 37) = 1.607, p = 0.213 $\eta^2 = 0.042$. There was no interaction between area and group F (1, 37) = 0.175, p = 0.678 $\eta^2 = 0.005$. There was no interaction between condition and area F (1, 37) = 1.817, p = 0.186 $\eta^2 = 0.047$. There was no interaction condition x area x group F (1, 37) = 0.143, p = 0.708 $\eta^2 = 0.004$.

## 7.14 Discussion

Research in social attention has shown a strong bias to the face area (End & Gamer, 2019; Flechsenhar et al., 2018; Foulsham et al., 2010; Foulsham & Sanderson, 2013; Vo et al., 2012). These outcomes are also observable when using dynamic stimuli (Foulsham et al., 2010; Foulsham & Sanderson, 2013; Freeth et al., 2013; Klin et al., 2002). However, the absence or presence of the auditory information may play an important role when watching naturalistic videos in a group conversation, and for that reason, participants might strategically fixate less or more when this information is presented (Foulsham & Sanderson, 2013). In ASD, however, there is extensive evidence of avoidance behaviour towards the eyes area (Chita-Tegmark, 2016a, 2016b; Freeth et al., 2013; Klin et al., 2002). Although ASD and ADHD share symptoms and have a high prevalence of co-occurring (Antshel et al., 2016; Jang et al., 2013), there is evidence that both disorders should be studied separately and in case of their comorbidities as a separate identity (Seernani et al., 2021). To date, there has been no formal attempt to manipulate the extent to which participants attend to videoclips in group conversation having the eyes occluded and how such manipulation may be manifested in traits of ADHD and ASD.

The purpose of the current chapter was threefold: (1) to explore the effect of occluding the eyes on the conversation (2) the effects of auditory information on the conversation and (3) assess any differences this had on high trait and low trait of ADHD and ASD individuals within a community sample. There were four main results. First, we found no differences in looking to the social areas (targets as a whole), with around 99% of fixations being on targets in all trials. In both clip conditions and participant groups, there are extremely high percentages of fixations to targets were observed in line with previous chapters and previous literature of attention to social aspects (End & Gamer, 2019;

Flechsenhar et al., 2018). It is not surprising given that the targets were the only moving and social element within the scene. Furthermore, we may have expected a different pattern in ADHD and ASD group in fixations to the social stimulus (Freeth et al., 2013; Klin et al., 2002),. In fact, these results are in line with our previous chapters that we did not find a difference in high and low traits of ADHD individuals when attending to social stimuli. However, we cannot rule out the possibility that these results might be due to the fact that the targets collectively take up a large proportion of the screen, thus making it difficult to the participants to look elsewhere.  Another possible explanation behind the findings might be that high trait ADHD participants show less of an avoidance response in third-party viewing, where they are not actively engaging in conversation. For example, perhaps ADHD and ASD high traits are more able to explore the scene without any implied or explicit social presence.

Second, the findings in Experiment 7 and 8 were similar when analysing targets who were currently speaking. In both experiments, there were more looks to the sunglasses condition over the control condition. Although, there is research demonstrating the importance of having the eyes visible over eyes occlusion with sunglasses for social communication (Boucher et al., 2012). It seems that in this study the sunglasses attracted more attention because they were more prominent.

Third, the findings when analysing specific areas i.e., eyes and mouth were informative of this social prioritisation. In experiment 7, participants looked more to the eyes than the mouth. This is in line with previous research (Birmingham et al., 2009; Vo et al., 2012). However, in this experiment participants remain looking to the eye area in the Sunglasses condition, despite not being able to view the eyes to gain information. It is plausible that participants looked more to the eyes in the Sunglasses condition as a habit or a novel aspect of the scene. Furthermore, ASD-LT participants looked at the eyes and mouth areas more than the ASD-HT individuals, corroborating this avoidance behaviour in ASD individuals to these areas as reported previously (Chita-Tegmark, 2016b; Klin et al., 2002).

Fourth, in both experiments we found mixed results in targets whilst speaking in eyes and mouth area. In experiment 7, participants looked more to the eyes (than the mouth) in the sunglasses compared the control condition. Here, the ASD-LT made more fixations to both areas (eyes and mouth) in comparison to the ASD -HT group. In Experiment 8, when these targets were speaking, there were more looks to faces (eyes and mouth) in the Sunglasses condition than the Control condition. In line with the evidence, that ambiguous stimuli (in this case sunglasses) attract attention in a reflexive way (Ristic & Kingstone, 2005), but in addition, demonstrates this effect is observable in a larger group setting rather than static or more simplistic stimuli. The two experiments gave the opportunity to explore the effect of occluding the eyes in conversation following whilst comparing two sub clinical sample of interest ADHD and ASD individuals. We demonstrated that although overall there are minimal unexpected visual attention patterns in overall looks to targets and speakers, there are some diverging results upon deeper analysis. The results highlight the complexities of studying subclinical samples on visual attention and the different ways social attention and gaze following presents in high trait and low trait populations.

In conclusion, we examined the effects of occluding the eyes in conversation on traits of two subclinical samples ASD and ADHD. Our results show that during dynamic stimuli the social object was fixated to a greater degree than the other areas of the videoclips. Furthermore, auditory information, eyes occlusion and the subclinical samples affect to some degree the prioritisation in some areas (eyes and mouth) of the videoclips. Such findings suggest that occluding the eyes in social conversation in dynamic stimuli can counteract the avoidance of attending to the eyes and mouth areas.

# Chapter 8
# Evidence for ADHD traits related to maintenance in an online working memory task

**Abstract**

In this chapter, I investigated two components of WM (maintenance and distractor processing) and their association with ADHD-like traits within the general population. I administered a behavioural online study measuring accuracy and reaction times, and a questionnaire measuring ADHD traits to 250 participants. The WM task had two levels of maintenance (1 sec vs 9 sec) and distractor processing (presence or absence). I tested the hypothesis that the difference between components of WM would be related to ADHD traits. The results demonstrated that ADHD traits was only related to the difference in maintenance but not in distractor processing.

## 8.1 Introduction

Previously, we have reviewed that WM can be conceived as the ability to manipulate and store a limited amount of perceptual information during brief input disruptions in order to provide an integral representation of the memorised information (Baddley & Hitch, 1974; Evans & Baddeley, 2018). Without this ability, we could not remember a face of a colleague among others in a meeting or follow a conversation. This chapter considers the nature of remembering perceptual information i.e., a face in detail, concentrating on two primary components: (1) maintenance (i.e., having to remember something for a specific interval) and (2) distractor processing (i.e., having to ignore an irrelevant stimulus). Furthermore, this chapter considers how individual differences are related to task performance. The present work was partly influenced by Yoon, Grandelis and Maddock's (2016) research on the amount of gamma-aminobutyric acid (GABA) in an individual's prefrontal cortex while performing a WM task. Participants viewed cues (1 vs 2 faces) which had to be memorised across a delay period (1 vs 9 s) to make a match discrimination with a probe face presented at the end of the trial. In some trials, a distractor or irrelevant face was presented. Accuracy in the task dropped from 99.6% in trials with a single cue to below 80% for longer intervals and when a distractor was presented. They reported that participants with higher GABA levels in the dorsolateral prefrontal cortex were more accurate with a greater amount of information than those participants with lower levels. Their findings led to further experimentation in the clinical population (e.g., Dienel & Lewis, 2019). The important implication of Yoon et al results for our purposes is the fundamental distinction between the components of WM, especially when using stimuli such as faces.

Despite extensive research  using faces on emotion identification (e.g., Curby et al., 2019; Pecchinenda & Petrucci, 2016), the precise cognitive significance of faces remains an important matter of research for visuo-spatial working memory (VWM) tasks. Faces are complex visual-spatial stimuli that provide social and emotional information and play a crucial role in social interaction and communication (Curby et al., 2019; Jackson & Raymond, 2008; Smyth et al., 2005). Furthermore, face can be identified easily after short periods and are difficult to verbalise. Thus, making suitable stimuli for examining the visuospatial component (Smyth et al., 2005). In the following sections, I will be presenting evidence based on the extent to which maintenance (different delay periods) and distractor processing impacts control mechanisms of visual attention.

## *To what extent do delay periods impact attentional control mechanisms?*

Current theories claim that control mechanisms of visual attention are actively linked to the maintenance of information. Consistent with this notion, it has been suggested that attention prevents decline by refreshing the activity of memorising information (Baddley & Hitch, 1974; Hakim et al., 2020; Smyth et al., 2005). Another possible explanation is that during the delay, attentional resources protect against the interference of irrelevant stimuli (Forster et al., 2014; Konstantinou & Lavie, 2020). The sudden-death theory proposes that visual items are kept in memory some moment in time and suddenly lost in a 'sudden death' fashion way (Donkin et al., 2015; Hakim et al., 2020; W. Zhang & Luck, 2009). Zhang & Luck, (2009) used a short-term recall paradigm and participants were asked to retain three coloured squares in WM. After different delay periods, one of the items is cued, and participants reported the colour by clicking on a colour wheel. This model assumes that when a participant has a memory of a cued item, the response tends to be closed to the value of the actual stimulus, and the distribution of responses over trials is normally distributed around the actual value. Essentially, the standard deviation is a sensitive value to determine the decline of the memory representation. Therefore, the standard deviation is inversely proportional to the precision of the representation. This model also provides evidence that items held in WM within 4s delay had little loss (Zhang & Luck, 2009). Hakim et al., (2021) used a trial-to-trial analysis to examine the maximum number of items that one's can maintain, and the probability of achieving that maximum. They asked participants first to read out loud a series of digits, then to memorise an array of six coloured squares for 150 ms. After a retention interval was presented (1.5 vs 10 s), participants were asked to report the colours of each square. Their results showed that poor performance after longer intervals reflects an inability to maintain attentional control throughout the retention interval, not a limited capacity of memorising items on WM. Smyth et al., (2005) asked participants for a serial reconstruction of the order of presentation of faces (3,4,5 and 6) after a retention interval (2 vs 6 s). In their experiment, three conditions were tested: articulatory suppression, spatial tapping and a control condition. Their results showed serial position effects when faces were presented for 300 ms and after a 6-s retention interval. Furthermore, functional neuroimaging studies are consistent with the notion of the link between visual attention and maintenance (Awh & Jonides, 2001; Gazzaley et al., 2004; Geier et al., 2009; Miller & D'Esposito, 2005; Sreenivasan & D'Esposito, 2019). This notion comes from the activation of anatomical brain areas when performing such task. Geier et al., (2009) used a memory-guided saccade task and examined the brain areas involved in different delay periods (2.5 vs 10 s) in adults, adolescents and children. Their results demonstrated that areas such as cortical eye fields, posterior parietal cortex and prefrontal cortex (PFC) areas were active for both short and long delays across all age groups. Together these studies suggest that attention and WM are strongly associated during the retention interval as demonstrated by the activation of the same brain areas. Moreover, longer intervals (greater than 4s) lead to worse performance because people have to maintain information in WM.

The PFC and parietal cortex are crucial brain areas when studying control mechanism. Both areas are also implicated in balancing persistent activity in the face of a distractor (Lorenc et al., 2021; Sreenivasan & D'Esposito, 2019). The PFC and parietal cortex will be described in further detail in the next section.

## *To what extent does distraction impact the performance of control mechanisms?*

Previously, I have described the role of the PFC when maintaining information during different intervals. In this section, I present evidence of control mechanisms that actively prevents information to be remembered. In this line, control processes may serve as a filter or blockage for task-irrelevant input from being encoded into WM and interfering with actual representations (Konstantinou & Lavie, 2020; Lavie, 2010).

In terms of performance, perceptual interference can impact WM in a general disruption when memorising low-level (Forster et al., 2014; Konstantinou et al., 2014) or high-level stimuli such as faces and scenes (Cronin et al., 2020; Hancock et al., 2000; Ritchie et al., 2021). Interestingly, however, it has been suggested that when distractors and memoranda share a certain level of properties, memory responses show a preference towards the distractor a term referred to as attractive bias (Lorenc et al., 2021; Mallett et al., 2020). Perhaps the distinctive work from (Mallett et al., 2020) provides a better understanding of this tendency in faces. In their study, participants performed a delayed-estimation task using faces that varied along the dimension of age and gender. Participants were asked to memorise a face, followed by a distractor which can be located either clockwise or counter clockwise. Following the delay, participants selected the memory target from a continuous wheel. The authors tested in three different experiments which varied on the location angle of the distractor. In the three experiments, the authors found a similar performance across the experiments.  The tendency to respond was in fact towards the distractor and not to the cue. Whereas it is commonly assumed that distractors may influence the performance of a task, this influence depends on the interaction between the memorised cue and the distractor which could be either attracted or rejected.

These hypotheses on face processing have been received empirical support from clinical studies (Alderson et al., 2013; Dienel & Lewis, 2019) Specifically, in ADHD as traits or state, it has been suggested difficulties in distraction resistance and maintenance (Faraone, 2000; Oosterlaan et al., 1998; Sergeant et al., 2003).  Studies assessing adults diagnosed with ADHD vs non-ADHD report lower performance on VWM task  (Alderson et al., 2013; Kim et al., 2014; van Ewijk et al., 2014). While one recent study found slower reaction times in a group with ADHD traits relative to a control group (Jang et al., 2020), further investigation on ADHD traits is required to confirm the different behavioural response. In previous chapters, there were not many effects of ADHD traits in cognitive load or in the image-viewing task. Although, chapter 6 provides evidence for attentional deployment in a non-social object related to the degree of ADHD. Chapter 6 does not examine WM. In here, I examine the separate 'load' components. To this end, this chapter examines the behavioural responses on a community sample with ADHD traits while performing a VWM task online. Considering that faces are difficult to verbalise in order to be remembered, we use faces as stimuli. Yet, research on ADHD as a clinical entity or traits have used faces to understand emotional identification and processing (Dan & Raz, 2018; Kleberg et al., 2020; Raz & Dan, 2015; Tye et al., 2013). Little is known regarding the impairments in components of VWM on traits of ADHD.

## 8.2 Experiment 9

The main aim of the present chapter was to investigate the relationship in maintenance (i.e., having to remember something for a longer interval) and distractor processing (i.e., having to ignore a distractor) with the individual differences in ADHD traits within the general population. To this end, I asked participants (n = 233) to complete a VWM online task. According to the sudden-death theory (Donkin et al., 2015; Hakim et al., 2020; Zhang & Luck, 2009), long delays should disrupt VWM performance. If longer retention intervals impact working memory performance via fluctuations in attentional control and ADHD is characterised by impairments in WM and attentional control, then we expect to find that people with higher scores of ADHD are more affected by the delay (as a difference between the long and short delay) than people with lower scores of ADHD. According to the distractor bias in faces (Mallett et al., 2020), when cue and distractor are relatively similar there is a tendency to memorise the distractor. If that is the case in our paradigm, then participants should be slower (as distractor and cue are interfering) in distractor presence over the absence. Otherwise, we expect to find quicker reaction times in the absence over the presence of the distractor. In terms of ADHD-traits, these findings could provide further evidence of their behavioural response.

## 8.3 Method

## 8.4 Participants

We collected 233 participants through the Prolific Platform (https://www.prolific.ac/) and from the University participant pool. Written (digital) informed consent was obtained from all participants prior to participation. All participants were aged between 18 to 59 (mean age: 30.18 years, SD = 10.95 years, 144 female). All participants were provided with an information sheet and completed a consent form before the start of the study.

## 8.5 Materials and Task Design

We designed and conducted the experiment online using the Gorilla.sc research platform (www.gorilla.sc/about). The task was modified from that created by Yoon, et al (2016). In the task participants were asked to remember the emotion of a (cue) face so that they could decide whether it matched a later presented (probe) face. In each trial, the cue was presented first, and this could be one or two of emotional faces (taken from the Stirling face database; www.pics.stir.ac.uk). After a delay period, the probe face was presented either the same emotional expression or a different expression (with a match on 50% of trials). The probe face was the same identity as the cue. The dependent variables were the accuracy at detecting the match and the reaction time to do so. There was a total of eight different versions formed by a combination of the following factors: the visual perceptual load (one or two cue faces); (b) the length of the delay (short or long delay); (c) the presence or absence of a neutral distractor face. Only the factors of delay and distractor were of theoretical interest.

## 8.6 Procedure

Participants were asked to respond to the ASRS (Kessler et al, 2005) before the experimental phase. Figure 23 illustrates the procedure underlying the experiment. The experimental phases consisted of the following sequence. A fixation dot was displayed for 250 ms, followed by a memory set for 2000ms a face was presented. In the maintenance period, a fixation dot was then presented for either 1000ms or 9000ms. In half of the trials a distractor was presented in the maintenance period. For the shorter maintenance period, the fixation dot was presented for 1000ms and then the distractor for 1000ms followed by 250ms of fixation dot. For the longer maintenance period, the fixation dot was presented for 4500 ms and then the distractor for 1000 ms followed by 4500ms of fixation dot. After a probe was presented, participants were required to respond whether that probe represented the same emotion as the memory cue by pressing ‘z’ for yes and ‘x’ for no. After the response (or on termination of the 2000 ms time window, in cases of a missed response), the following trial was then presented. The experiment consisted of eight blocks. Each block consisted of 12 trials. All participants completed all conditions which were presented in a random order. The task took about 20 minutes


*Figure 23 Schematic representation of the stimuli and procedure. This condition is long delay and distractor presence.*

## 8.7 Data Analysis and Results

Only participants who scored above chance in the task were included in the analysis. We only analysed data from 220 participants. Table 27 presents the accuracy of the task as a function of the components: delay (short and long) and distractor (present and absent). From the table 27, it can be seen that the pattern is the same, the short/absent condition is the easiest and the long/present condition is the hardest.

| WM | Short delay | Long delay |
|---|---|---|
| Distractor absence | 90.81 (14.86) | 73.50 (14.16) |
| Distractor presence | 85.61 (16.12) | 68.65 (14.74) |

*Table 27 Mean accuracy on the task as a function of the WM components; delay (short and long) and distractor (present and absent).*

### *8.7.2 The effects of components on RT*

| WM | Short delay | Long delay |
|---|---|---|
| Distractor absence | 919.59 (223.89) | 1045.01 (278.09) |
| Distractor presence | 1031.22(226.83) | 1061.53 (231.11) |

*Table 28 Mean accuracy on the task as a function of the WM components delay (short and long) and distractor (present and absent).*

Participant means were entered into a within-subject ANOVA (means and standard deviations are presented in Table 28) with the factors of maintenance (short and long) and distractor (presence or absence). There was a significant main effect of maintenance $F(1, 219) = 30.267$, $p = 0.001$ $\eta^2 = 0.121$, indicating that participants were quicker in the short delay over the long delay. There was a significant main effect of distractor $F(1, 219) =$

33.112, $p = 0.001$ $\eta^2 = 0.131$, indicating that participants were slower in the presence of a distractor over the absence. There was an interaction between maintenance and distractor $F(1, 219) = 16.888$, $p = 0.001$ $\eta^2 = 0.072$.

### *8.7.3 The relationship between WM and ADHD traits*

Scores from the ASRS was on average 47.70 (SD = 9.33). To quantify task performance sensitivity in each of the components, the following changes were calculated: (1) $\Delta$ *de* = RT in the long delay – RT in the short delay; (2) $\Delta$ *dis* = RT distractor presence – RT distractor absence. The $\Delta$ *de* was on average 75.17 (SD = 202.21) and the $\Delta$ *dis* was on average 67.07 (SD = 166.74). The ASRS were positively correlated with the delay difference $r(220) = 0.171$, $p = 0.011$ as shown in Figure 24. This suggest that people with high traits of ADHD were more affected by the delay than people with low traits of ADHD. We did not find a relationship between the difference in distractors and the ASRS $r(220) = -0.064$, $p = 0.348$.

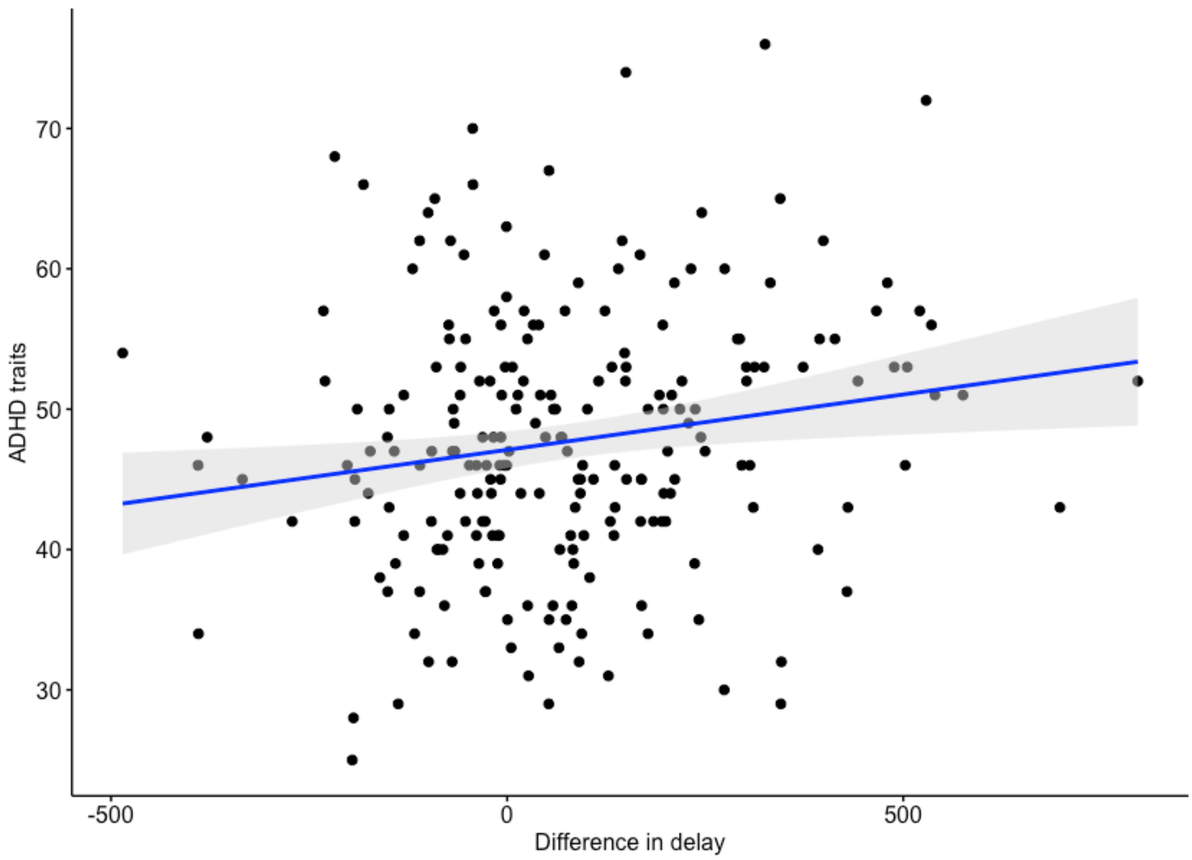


*Figure 24 Correlation between the difference in delay and ADHD traits.*

## 8.8 Discussion

In the present chapter, I investigated the association in maintenance and distractor processing with the individual differences in ADHD traits within the general population. There were three main results. First, this study demonstrated that higher differences in delay (long vs short) were related to higher traits of ADHD. This impairment suggests that maintaining a face in memoranda for longer intervals placed an increasing burden on WM that harmed cue retrieval, and that this had a larger effect in those participants with higher scores of ADHD. Second, the presence of the distractor slowed responses in the participants, suggesting that perceived irrelevant faces do impact the retrieval of the cue. Third, this study reported the difference in distractor processing (presence vs absence) was not related to traits of ADHD. These results might imply that the ADHD has an effect on maintenance but not distractors.

The findings of the delay impairments related to the severity of ADHD are consistent with previous studies examining the traits (e.g., Jang et al., 2020) and the state of this disorder (Herrmann et al., 2009). Some studies have suggested impairments in the spatial WM in ADHD  (Fosco et al., 2020; Jang et al., 2020; Kim et al., 2014; Sonuga-Barke et al., 2002; van Ewijk et al., 2014; Westerberg & Klingberg, 2007; Woltering et al., 2021) Although (Fosco et al., 2020) is the only one who has studied the different impairments that ADHD exhibits in WM, they use several WM tasks to account for these components, making it complex to understand the specificity of the WM. In this study, we provide evidence that the impairments in maintenance increase with the severity of the symptoms. Contrary to (Sonuga-Barke et al., 2002) study on which WM was not associated with ADHD symptoms in preschool children. This study provides evidence that WM could be deteriorate in adults with symptoms of ADHD.

These findings provide evidence that perceptual inputs i.e., faces can disrupt the active maintenance of information in WM similar to simple feature displays (Konstantinou & Lavie, 2020; Lorenc et al., 2021; Olivers et al., 2006). The WM long delay disruption experienced in participants with high traits fits well in the ADHD literature, especially in the delay aversion hypothesis (Shoham et al., 2020; Sonuga-Barke et al., 1992, 2002). This hypothesis is based on the assumption that people with ADHD may have a steep delay of reinforcement gradient. If a prolonged time is a problem in ADHD, this can be explained by the results in this study as it might be plausible that WM may be only affected in longer delays. The present study found no evidence of a relationship between distractor processing and ADHD symptoms. This could be due to the difficulty of the task. The accuracy task dropped drastically from 90% to 68% distractor presence vs absence, probably owing to floor effects. The lack of an effect of ADHD traits on face distraction can be due to faces are prioritised in attentional deployment. Therefore, these stimuli can be difficult to be distracted at as shown in previous chapters.

The current study investigated the relationship between the components of WM (maintenance and distractor processing) and the traits of ADHD. While there was a relationship between ADHD severity and the difference in maintenance, the distractor seems not to be related to the traits of the disorder. Given the current data from this study, I provide insights into the use of faces for examining the different components of WM as well as an understanding of the traits of ADHD in a community sample.

# Chapter 9
# General Conclusions

## 9.1. Summary of main findings

The present thesis provides a new view of the nature of attention mechanisms and cognitive load in viewing behaviour. The main research question that guided the formation of this thesis was: how a social object, non-social object, cognitive load and ADHD symptoms affect overall eye movements behaviour in complex scenes (images and videos)? Here, I present the main findings of each chapter:

In **chapter 3,** this thesis reports a successful replication of Lavie et al (2004) indicating the interplay between cognitive load and distractor avoidance.

In **chapter 4**, this thesis reports the social prioritisation remains stronger regardless of cognitive load or salience information. Also, this chapter does not find any difference in the non-social object with high and low salience information. Interestingly, cognitive loads do not have an effect on the image-viewing task. Furthermore, ADHD-like traits were related to fewer fixations on the social object, but only in the low memory load and high salient condition.

In **chapter 5**, this thesis reports a social bias (as a function of greater number of fixations to this area) whilst viewing a scene. However, when memorising low loads of information participants were likely to fixate even more to this social area. In this chapter, the salience effect is overridden for the cognitive load. Furthermore, ADHD-like traits were related to fewer fixations on the non-social object in the high memory and high salient condition.

In **chapter 6**, this thesis confirms the strong prioritisation of social information in scenes. By using the 'do not look' instruction, there was evidence of more errors (in total percentage and in early viewing) in social areas over the non-social areas (under the corresponding restriction conditions). Salience estimates did not affect eye movements. Furthermore, ADHD-like traits and MW were related to greater fixations on the non-social areas in the free-viewing condition. The 'do not look' task complements existing paradigms that examine attentional deployment (Stroop, go/no go, anti-saccade). Interestingly, however, this paradigm provides a novel method by using natural complex stimuli. Contrary to the anti-saccade task which only measures the time before the onset presentation, this method provides an extensive insight into attentional deployment for longer periods of time.

In **chapter 7,** this thesis reports the effects of occluding the eyes in conversation. In particular, this study groups participants based on two different subclinical traits (ADHD and ASD) and compares them based on the levels of symptoms. The results show a greater percentage of fixations on the eyes in the sunglasses over the control condition and to the eyes over the mouth area. Furthermore, the study reports differences between ASD-HT and ASD-LT suggesting that occluding the eyes in conversation reduces eye avoidance in ASD-HT.

In **chapter 8**, this thesis reports a relationship between the differences in delay (short vs long), but not a relationship between distractor processing and traits of ADHD. These results suggest that participants with higher scores of ADHD have difficulties maintaining a face in memoranda for longer interval.

### *9.1.1 The implications in the findings*

In understanding the results it is also useful to consider recent theoretical debates around attentional control and the meaning of the terms top-down and bottom-up (Benoni 2018; Benoni & Ressler, 2020; Gaspelin, & Luck 2018; Theeuwes, 2018; Egeth, 2018). Some authors (e.g., Theeuwes, 2018) emphasise the importance of whether the control of attention is voluntary or involuntary and argue from the existence of involuntary control of attention, that may occur despite our temporary goals to the contrary, that there are important limits to the influence of top-down goals on attentional control. Others (e.g., Benoni, 2018; Benoni & Ressler, 2020) argue that the control of attention is fundamentally driven by the relevance of the stimuli to our goals, but these goals are sometimes implicit such that we may not be aware of them or deploy them deliberately. Benoni and Ressler (2020) suggest that by combining this implicit-explicit dimension, with a second dimension that captures the timescale over which a particular goal applies, most phenomena of attentional control can be explained. On this account traditional forms of top-down control of attention where specific task relevant goals are loaded into working memory would be considered explicit and temporary. The results from this thesis point out that the preferential looking towards the social object may best be characterised as the result of an enduring implicit goal. The current results are then consistent with the idea that the expression of such an enduring implicit goal can occur even in the face of a high cognitive load. The framework proposed by Benoni and Ressler (2020) may be useful in that it explains how both "low-level" physical and "high-level" social stimuli can influence attention according to fundamentally similar processes.

## *9.1.2 The social prioritisation on the image-viewing tasks*

In most of the experiments in this thesis, there was a strong bias towards the social element of the scenes even in the presence of salience information and memory load. Experiment 3, 4 and 5 differ in the type of cognitive load (verbal or visuospatial) and presentation (sequential or simultaneous). However, the percentage of fixating in the social areas did not vary in the low load between 41% and 44% in the three experiments. But, when high loads of information were in memoranda, this percentage was between 32% to 41%. From the time courses in these three experiments, it is evident that the social bias is stronger early on time (>45%), and it remains between 38% and 43% until the 15$^{th}$ fixation. The experimental results suggest that the presence of a social element is highly detected when facing salience information and cognitive load in complex scenes.

This finding points to the idea that the rapid attention to social elements relies on the 'feedforward' process (Lamme & Roelfsema, 2000; Sugase et al., 1999; Rossion et al., 2015). This process through the visual cortical hierarchy rapidly activates high-level neurons selective to social elements (Lamme & Roelfsema, 2000). VanRullen, (2007) suggested that even in the absence of attention, the cortical activation support recognition and categorization of the elements within the display without giving rise to conscious perception. Another suggestion is that social prioritisation is the consequence of an automatic process (Laidlaw et al., 2011, 2012; Laidlaw & Kingstone, 2017). In Experiment 5, participants made more errors avoiding to social elements than non-social elements. I also reported a strong bias in the first second of the image presentation during the restricted and the free viewing condition (Experiment 5). This early bias has been reported between 120 and 400 ms after stimulus presentation (e.g., Rossion et al., 2015), The restricted conditions are crucial because these conditions required participants to look against the natural inclination in viewing. this condition place automatic and volitional behaviour in a direct competition. Furthermore, this social bias is also sensitive in the real-world dynamic stimuli, such as video recordings of people having a conversation (as demonstrated in Experiment 6 and 7). From these Experiments, it is clear that when looking at a scene with the presence of a social element, one generates an automatic process in feedback to a lower hierarchical level, altering the subsequent sweep and looking directly to this social element before analysing the scenes in detail (Lamme & Roelfsema, 2000; Sugase et al., 1999).

Furthermore, the results from simultaneous presentation (Experiment 4) suggest that the social advantage is a consequence of high perceptual loads (Konstantinou et al., 2014; Konstantinou & Lavie, 2013, 2020; Lavie et al., 2004; Lavie & Tsal, 1994). Therefore, the social advantage depends on the availability of perceptual resources, when these are allocated to the memory items. I suggest that social advantage may be reduced when memorising high loads of perceptual information, and it is not dependable of cognitive load processes. Considering the spectrum of attentional control view for understanding these results, the social advantage may be allocated by implicit goals, but in a manner that would be located in permanent temporality (Benoni & Ressler, 2020).

In the present thesis, I also examined the individual differences in ASD. This subclinical example shows an atypical response to eye gaze. The results from Experiment 7 go substantially beyond previous findings by showing that faces occluded with sunglasses facilitate looking at the eyes of others in individuals with high traits of ASD. In fact, eyes occlusion seems to accelerate this automatic process to social elements. This might be due to sunglasses are a novel item to look at in a group conversation.

### *9.1.3 The null salience on the image-viewing tasks*

In the image-viewing Experiments, I reduced or increased the salience information of the non-social element in the scenes. This was done considering the three simulated fixations from the Saliency Toolbox (Walther & Koch, 2006). In these experiments, there was no influence of salience information when memorising high nor low cognitive load. Two possible explanations for these results include the influence of cognitive load and social attentional biases. First, eye movements may have been influenced by cognitive load. It is possible that participants were trying to avoid looking to the non-social element regardless of the salience information as these might be distracting for keeping in memoranda the information (Lavie et al., 2004). Second, the social bias might have overridden the salience effect, since the social bias and the salience effect occur early on time (Donk & van Zoest, 2008; Laidlaw et al., 2012).

Aside from the inclusion of the social stimuli, there are some differences to consider. The typical implementation of the flanker task involves multiple locations. In chapter 3, I only used one location. In fact, there were only two elements presented on the screen whereas the scene stimuli from Chapter 4, 5 and 6 were much richer in nature. In these chapters, there is not an explicit task. It is therefore unclear which object it should be the equivalent of the flanker task. If it is the social object, there is clearly a bias towards this area (which has been discussed in the previous section). If it is the non-social object, then this is clearly less preferred than the social object. It is possible that the salience of the non-social highly salient object is still not high enough to make it a potent competitor. Thus, the effect is not observable. Yet I went to great lengths to define the physical salience of this object in terms of predicted fixations in an implemented model. It is unlikely that differences in the basic stimulus properties like image complexity could explain the data. The more important difference in flanker task is an explicit goal to select the target and ignore the flanker, whereas in the free viewing task of Chapter 4 and 5 there is not. If the task of Chapter 4 and 5 were changed so that the task was to attend to the non-social object and avoid looking at the person, an effect of load would likely be observed. However, the aim of the thesis was not to investigate whether overriding our natural looking behaviour requires cognitive load, rather it was to investigate if the natural expression of the looking behaviour in a free viewing task recruits these resources.

### *9.1.4 The effects of Cognitive load on the image-viewing task.*

Classic models of search (e.g., biased competition model; Desimone & Duncan, 1995) propose a key role for a target template in WM. These studies have shown that placing a misleading item in WM can derail the search (Duncan & Humphreys, 1989; Olivers et al., 2006; Van der Stigchel & Hollingworth, 2018). Experiments 3,4 and 5 are not a search task and there is no target per se. However, it is important to consider that the social elements interference with this guidance process. In Chapter 4 and 5, I consider the relations between the ways in which WM (verbal and visuospatial) is recruited in these types of search theory and the role it plays in load theory. It was clear that verbal and visuospatial WM had different effects on (social) attention in complex images.

Although these results are consistent with the Load Theory (Konstantinou & Lavie, 2020; Lavie et al., 2004; Lavie & Tsal, 1994), there is reason to believe the pattern of results could have differed (between experiments) for several reason. Experiment 3 required verbal WM. It might be possible that these WM tasks do not interfere with the central executive system, and it was a reflection of the phonological storage itself (Baddeley, 2001; Baddley & Hitch, 1974). Experiments 4 and 5 required visuospatial WM, but these results differ due to their presentation. For instance, participants responded quicker to the simultaneous presentation than to the sequential presentation. These findings that visuospatial WM have an effect on attentional capture, but not in the phonological load, have been previously reported (Burnham et al., 2014).

### *9.1.5 ADHD Traits*

Research on ADHD and its cognitive impairments have building models based on the heterogeneity of cognitive impairments in this disorder (Barkley, 1997; Nigg, 2001; Sergeant et al., 2003; Sonuga-Barke et al., 2002). These models are based on the assumption that ADHD should be seen as an umbrella construct with the clinical value that sums alterations and overlapping cognitive profiles. Some of the cognitive profiles suggested to be altered are visual attention, working memory, inhibition and reward processing (Alderson et al., 2013; Gau & Shang, 2010; van Ewijk et al., 2014).Therefore, the heterogeneity is inferred from independent studies which work in a specific domain. Bearing that in mind, it is not surprising that the results from all the studies revealed inconsistent patterns among the performance of the image-viewing tasks and ADHD traits. In the image-viewing task (Experiment 3, 4 and 5), the high salient non-social element seems to be related to ADHD traits. However, the type of information (verbal vs visuospatial) and load (high vs low load) impact too in these relationships. Although there has been extensive research on WM and ADHD (Gau & Shang, 2010; Kasper et al., 2012; van Ewijk et al., 2014), this is the first study that provides evidence of the performance of an image-viewing task when loading information in ADHD traits.

Experiment 6 provides evidence that the Free viewing condition is a more sensitive instruction to detect individual differences in attentional impairment in ADHD and MW. In Hayes & Henderson, (2018)_study, they also detected individual differences in clinical traits in a Free-viewing condition consistent with our results. Experiment 8 provides evidence that participants with high traits of ADHD exhibit different pattern of eye movement behaviour comparing to ASD (Experiment 7). ADHD show less of an avoidance response in third-party viewing than ASD. It is possible that this type of interaction are more engaging to this specific subclinical sample, since it does not involve much of cognitive resources (Castellanos et al., 2006).

Due to the different patterns in the performance of the tasks and ADHD, Experiment 9 aimed to understand what might be affected in this subclinical sample based on WM components. I present evidence that individual differences in ADHD is related to WM long delay. Once again, it is important to consider the heterogeneity of the disorder, especially since I did not find a relationship with the presence of the distractor. However, it seems that Sonuga-Barke's hypothesis on the delay aversion fits well in this study (Shoham et al., 2020; Sonuga-Barke et al., 1992, 2002).

### *9.1.6 Proportional data implications*

In the experiments of this thesis, I have analysed the data based on the probability of fixating to either one region or another within the scene. However, there is a debate whether proportional data should be transformed (Douma and Weedon, 2019; Lin, & Xu, 2020; Warton and Hui, 2011). The main problem with proportional data is that variance is usually not constant across the dependent variable. By transforming the data arcsine-based (a standard procedure that uses the arcsine square root; Warton and Hui, 2011), we could yield a better approximation to the normal distribution and stabilize the variance (Lin, & Xu, 2020). However, we are dealing with a bias estimation and difficulties in interpretation. Douma and Weedon, (2019) provide an overview of the different techniques used when analysing binominal data by suggesting the implementing of Dirichlet regressions. Although correcting for ROI size is sometimes useful in eye tracking studies it is not always advisable because it relies on the assumption that larger areas are fixated more often, which does not always hold (see Hessels, Kemner, van den Boomen, & Hooge, 2016). In this thesis, it is noteworthy that there were about twice as many fixations on the social area even though it was roughly the same size.

It is also important to note that the main research question was not whether I would find a social advantage by comparing two different ROIs, instead I was interested in comparing the same ROIs in different load conditions. Since all images appeared in all load and saliency conditions, any differences in size could not explain any interactions with load.

## 9.2. Limitations and Future directions

While my studies are a step towards understanding the influence of cognitive mechanisms and clinical traits on scene viewing, there are some limitations. First, we examined participants reporting only symptoms of ADHD within undergraduates rather than participants diagnosed with ADHD. Research has shown that individuals who reported high traits of ADHD are likely to report similar impairments than those with the clinical diagnosis (Friedrichs et al., 2012). Also, we assessed ADHD-like symptoms based on the DSM – IV criteria. Future studies should assess with questionnaires based on the DSM – 5 criteria which reflect changing knowledge of the symptoms of the disorder. To date, many studies have focused on eye movement behaviour in the search for a target (Anderson et al., 2015; Foulsham & Underwood, 2009; Underwood et al., 2006). Researchers are starting to investigate the effect of cognitive load whilst image viewing (e.g. Cronin et al., 2020).

However, more research on the impact of cognitive load and complex stimuli, for instance, in videos and in-live setting are also needed. Moreover, studies need to explain underling cognitive mechanism such as the different types of working memory or the ability to avoid distractors within complex environments (as in the previous chapters). By using stimuli such as videos, we can determine what mechanisms underlie distractor processing and cognitive load in real life situations. For instance, by asking participants to memorise different loads of information whilst looking at naturalistic conversations. Furthermore, one interesting question by using the DL task (that arose while analysing data from Chapter 6) is whether participants with a Conduct Disorder or Antisocial behaviour would exhibit a contrary pattern to those with ASD. This might be interesting since these disorders are also comorbid with ADHD and are presented with affronting social behaviour (Castellanos et al., 2006). Another important future goal is to understand how emotion processing affects working memory components. This is crucial since ADHD has been also reported with emotion dysregulation, affecting their relationships and quality of life (Herrmann et al., 2009; Raz & Dan, 2015; Serrano et al., 2018). Finally, future studies should take into account the many confounding factors that could influence examining eye movements behaviour in clinical or subclinical samples such as: medication history and environmental factors.

## 9.3 Concluding remarks

In conclusion, these studies shed light on the underlying cognitive mechanisms of social attention using complex stimuli. Furthermore, they provide evidence which is pertinent for the understanding of social attention in subclinical samples with traits of ADHD and ASD. These findings suggest that attending to a social area in complex stimuli: (1) is not dependent on the availability of default voluntary top-down resources, (2) depends on the availability of perceptual resources, (3) is an automatic process, (4) can be facilitated by eyes occlusion to people with high traits of ASD, but not ADHD.

# References

Ahmad, J., Swan, G., Bowman, H., Wyble, B., Nobre, A. C., Shapiro, K. L., & McNab, F. (2017). Competitive interactions affect working memory performance for both simultaneous and sequential stimulus presentation. *Scientific Reports*, *7*(1), 4785. https://doi.org/10.1038/s41598-017-05011-x

Alderson, R. M., Kasper, L. J., Hudec, K. L., & Patros, C. H. G. (2013). Attention-deficit/hyperactivity disorder (ADHD) and working memory in adults: A meta-analytic review. *Neuropsychology*, *27*(3), 287–302. https://doi.org/10.1037/a0032371

Allison, C., Auyeung, B., & Baron-Cohen, S. (2012). Toward Brief "Red Flags" for Autism Screening: The Short Autism Spectrum Quotient and the Short Quantitative Checklist in 1,000 Cases and 3,000 Controls. *Journal of the American Academy of Child & Adolescent Psychiatry*, *51*(2), 202-212.e7. https://doi.org/10.1016/j.jaac.2011.11.003

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders, 5th Edition: DSM-5*.

Anderson, N. C., Ort, E., Kruijne, W., Meeter, M., & Donk, M. (2015). It depends on *when* you look at it: Salience influences eye movements in natural scene viewing and search early in time. *Journal of Vision*, *15*(5), 9. https://doi.org/10.1167/15.5.9

Antshel, K. M., Zhang-James, Y., Wagner, K. E., Ledesma, A., & Faraone, S. V. (2016). An update on the comorbidity of ADHD and ASD: A focus on clinical management. *Expert Review of Neurotherapeutics*, *16*(3), 279–293. https://doi.org/10.1586/14737175.2016.1146591

Ashwood, K. L., Gillan, N., Horder, J., Hayward, H., Woodhouse, E., McEwen, F. S., Findon, J., Eklund, H., Spain, D., Wilson, C. E., Cadman, T., Young, S., Stoencheva, V., Murphy, C. M., Robertson, D., Charman, T., Bolton, P., Glaser, K., Asherson, P.,

… Murphy, D. G. (2016). Predicting the diagnosis of autism in adults using the Autism-Spectrum Quotient (AQ) questionnaire. *Psychological Medicine*, *46*(12), 2595–2604. https://doi.org/10.1017/S0033291716001082

Awh, E., Belopolsky, A. V., & Theeuwes, J. (2012). Top-down versus bottom-up attentional control: A failed theoretical dichotomy. *Trends in Cognitive Sciences*, *16*(8), 437–443. https://doi.org/10.1016/j.tics.2012.06.010

Awh, E., & Jonides, J. (2001). Overlapping mechanisms of attention and spatial working memory. *Trends in Cognitive Sciences*, *5*(3), 119–126. https://doi.org/10.1016/S1364-6613(00)01593-X

Baddeley, A. (2003a). Working Memory: Looking back and looking forward. *Nature Reviews*, *4*.

Baddeley, A. (2003b). Working memory and language: An overview. *Journal of Communication Disorders*, *36*(3), 189–208. https://doi.org/10.1016/S0021-9924(03)00019-4

Baddeley, A. D. (2001). Is working memory still working? *American Psychologist*, *56*(11), 851–864. https://doi.org/10.1037/0003-066X.56.11.851

Baddley, A., & Hitch, G. (1974). Working memory. The psychology of learning and motivation. *New York, NY: Academic*.

Barkley, Russell. A. (1997). *ADHD and the Nature of Self-control*. Guilford Press.

Bast, N., Mason, L., Freitag, C. M., Smith, T., Portugal, A. M., Poustka, L., Banaschewski, T., & Johnson, M. (2020). Saccade dysmetria indicates attenuated visual exploration in autism spectrum disorder. *Child and Adolescent Mental Health.*, 11.

Beck, D. M., & Kastner, S. (2009). Top-down and bottom-up mechanisms in biasing competition in the human brain. *Vision Research*, *49*(10), 1154–1165. https://doi.org/10.1016/j.visres.2008.07.012

Behrmann, M., Geng, J. J., & Shomstein, S. (2004). Parietal cortex and attention. *Current Opinion in Neurobiology*, *14*(2), 212–217. https://doi.org/10.1016/j.conb.2004.03.012

Benoni, H., & Ressler, I. (2020). Dichotomy, Trichotomy, or a Spectrum: Time to Reconsider Attentional Guidance Terminology. *Frontiers in Psychology*, *11*, 2243. https://doi.org/10.3389/fpsyg.2020.02243

Bey, K., Lippold, J. V., Aslan, B., Hurlemann, R., & Ettinger, U. (2021). Effects of lorazepam on prosaccades and saccadic adaptation. *Journal of Psychopharmacology*, *35*(1), 91–99. https://doi.org/10.1177/0269881120972424

Bianchi, L. J., Kingstone, A., & Risko, E. F. (2020). The role of cognitive load in modulating social looking: A mobile eye tracking study. *Cognitive Research: Principles and Implications*, *5*(1), 44. https://doi.org/10.1186/s41235-020-00242-5

Birmingham, E., Bischof, W. F., & Kingstone, A. (2009). Saliency does not account for fixations to eyes within social scenes. *Vision Research*, *49*(24), 2992–3000. https://doi.org/10.1016/j.visres.2009.09.014

Bollimunta, A., Bogadhi, A. R., & Krauzlis, R. J. (2018). Comparing frontal eye field and superior colliculus contributions to covert spatial attention. *Nature Communications*, *9*(1), 3553. https://doi.org/10.1038/s41467-018-06042-2

Booth, T., Murray, A. L., McKenzie, K., Kuenssberg, R., O'Donnell, M., & Burnett, H. (2013). Brief Report: An Evaluation of the AQ-10 as a Brief Screening Instrument for ASD in Adults. *Journal of Autism and Developmental Disorders*, *43*(12), 2997–3000. https://doi.org/10.1007/s10803-013-1844-5

Borji, A., Sihite, D. N., & Itti, L. (2012). Quantitative analysis of human-model agreement in visual saliency modeling: A comparative study. *IEEE Transactions on Image Processing*, *22*(1), 55-69.

Boucher, J.-D., Pattacini, U., Lelong, A., Bailly, G., Elisei, F., Fagel, S., Dominey, P. F., & Ventre-Dominey, J. (2012). I Reach Faster When I See You Look: Gaze Effects in Human–Human and Human–Robot Face-to-Face Cooperation. *Frontiers in Neurorobotics*, *6*. https://doi.org/10.3389/fnbot.2012.00003

Bozhilova, N., Michelini, G., Jones, C., Kuntsi, J., Rubia, K., & Asherson, P. (2020). Context Regulation of Mind Wandering in ADHD. *Journal of Attention Disorders*, 108705472095671. https://doi.org/10.1177/1087054720956714

Bozhilova, N. S., Michelini, G., Kuntsi, J., & Asherson, P. (2018). Mind wandering perspective on attention-deficit/hyperactivity disorder. *Neuroscience & Biobehavioral Reviews*, *92*, 464–476. https://doi.org/10.1016/j.neubiorev.2018.07.010

Bundesen, C. (1990). A theory of visual attention. *Psychological Review*, *97*(4), 523–547.

Burnham, B. R., Sabia, M., & Langan, C. (2014). Components of working memory and visual selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *40*(1), 391–403. https://doi.org/10.1037/a0033753

Capozzi, F., & Ristic, J. (2021). Attentional gaze dynamics in group interactions. *Visual Cognition*, 1–16. https://doi.org/10.1080/13506285.2021.1925799

Cashdollar, N., Lavie, N., & Duzel, E. (2013). Alleviating Memory Impairment through Distraction. *Journal of Neuroscience*, *33*(48), 19012–19022. https://doi.org/10.1523/JNEUROSCI.1797-13.2013

Castellanos, F. X., Sonuga-Barke, E. J. S., Milham, M. P., & Tannock, R. (2006). Characterizing cognition in ADHD: Beyond executive dysfunction. *Trends in Cognitive Sciences*, *10*(3), 117–123. https://doi.org/10.1016/j.tics.2006.01.011

Chambers, C. D., Payne, J. M., Stokes, M. G., & Mattingley, J. B. (2004). Fast and slow parietal pathways mediate spatial attention. *Nature Neuroscience*, *7*(3), 217–218. https://doi.org/10.1038/nn1203

Chita-Tegmark, M. (2016a). *Attention Allocation in ASD*. 16.

Chita-Tegmark, M. (2016b). Social attention in ASD: A review and meta-analysis of eye-tracking studies. *Research in Developmental Disabilities*, 15.

Christoff, K., Irving, Z. C., Fox, K. C. R., Spreng, R. N., & Andrews-Hanna, J. R. (2016). Mind-wandering as spontaneous thought: A dynamic framework. *Nature Reviews Neuroscience*, *17*(11), 718–731. https://doi.org/10.1038/nrn.2016.113

Cronin, D. A., Peacock, C. E., & Henderson, J. M. (2020). Visual and verbal working memory loads interfere with scene-viewing. *Attention, Perception, & Psychophysics*, *82*(6), 2814–2820. https://doi.org/10.3758/s13414-020-02076-1

Crosbie, J., Arnold, P., Paterson, A., Swanson, J., Dupuis, A., Li, X., Shan, J., Goodale, T., Tam, C., Strug, L. J., & Schachar, R. J. (2013). Response Inhibition and ADHD Traits: Correlates and Heritability in a Community Sample. *Journal of Abnormal Child Psychology*, *41*(3), 497–507. https://doi.org/10.1007/s10802-012-9693-9

Crouzet, S. M. (2010). Fast saccades toward faces: Face detection in just 100 ms. *Journal of Vision*, *10*(4), 1–17. https://doi.org/10.1167/10.4.16

Curby, K. M., Smith, S. D., Moerel, D., & Dyson, A. (2019). The cost of facing fear: Visual working memory is impaired for faces expressing fear. *British Journal of Psychology*, *110*(2), 428–448. https://doi.org/10.1111/bjop.12324

Dan, O., & Raz, S. (2018). Response Patterns to Emotional Faces Among Adolescents Diagnosed With ADHD. *Journal of Attention Disorders*, *22*(12), 1123–1130. https://doi.org/10.1177/1087054715606215

Della Sala, S., Gray, C., Baddeley, A., Allamano, N., & Wilson, L. (1999). Pattern span: A tool for unwelding visuo–spatial memory. *Neuropsychologia*, *37*(10), 1189–1199. https://doi.org/10.1016/S0028-3932(98)00159-6

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, *18*, 193–222.

Di Giorgio, E., Turati, C., Altoè, G., & Simion, F. (2012). Face detection in complex visual displays: An eye-tracking study with 3- and 6-month-old infants and adults. *Journal of Experimental Child Psychology*, *113*(1), 66–77. https://doi.org/10.1016/j.jecp.2012.04.012

Dickinson, C. A., & Intraub, H. (2009). Spatial asymmetries in viewing and remembering scenes: Consequences of an attentional bias? *Attention, Perception, & Psychophysics*, *71*(6), 1251–1262. https://doi.org/10.3758/APP.71.6.1251

Dienel, S. J., & Lewis, D. A. (2019). Alterations in cortical interneurons and cognitive function in schizophrenia. *Neurobiology of Disease*, *131*, 104208. https://doi.org/10.1016/j.nbd.2018.06.020

Dobrosavljevic, M., Solares, C., Cortese, S., Andershed, H., & Larsson, H. (2020). Prevalence of attention-deficit/hyperactivity disorder in older adults: A systematic review and meta-analysis. *Neuroscience & Biobehavioral Reviews*, *118*, 282–289. https://doi.org/10.1016/j.neubiorev.2020.07.042

Donk, M., & van Zoest, W. (2008). Effects of Salience Are Short-Lived. *Psychological Science*, *19*(7), 733–739. https://doi.org/10.1111/j.1467-9280.2008.02149.x

Donkin, C., Nosofsky, R., Gold, J., & Shiffrin, R. (2015). Verbal labeling, gradual decay, and sudden death in visual short-term memory. *Psychonomic Bulletin & Review*, *22*(1), 170–178. https://doi.org/10.3758/s13423-014-0675-5

Douma, J. C., & Weedon, J. T. (2019). Analysing continuous proportions in ecology and evolution: A practical introduction to beta and Dirichlet regression. *Methods in Ecology and Evolution*, *10*(9), 1412-1430.

Downing, P. E. (2000). Interactions Between Visual Working Memory and Selective Attention. *Psychological Science*, *11*(6), 467–473. https://doi.org/10.1111/1467-9280.00290

Duncan, J., & Humphreys, G. W. (1989). *Visual Search and Stimulus Similarity*. 26.

Dundas, E. M., Plaut, D. C., & Behrmann, M. (2013). The joint development of hemispheric lateralization for words and faces. *Journal of Experimental Psychology: General*, *142*(2), 348–358. https://doi.org/10.1037/a0029503

Egeth, H. (2018). Comment on Theeuwes's Characterization of Visual Selection. *Journal of Cognition*, *1*(1), 26. https://doi.org/10.5334/joc.29

Eimer, M. (2000). The face-specific N170 component reflects late stages in the structural encoding of faces: *NeuroReport*, *11*(10), 2319–2324. https://doi.org/10.1097/00001756-200007140-00050

End, A., & Gamer, M. (2019). Task instructions can accelerate the early preference for social features in naturalistic scenes. *Royal Society Open Science*, *6*(3), 180596. https://doi.org/10.1098/rsos.180596

Engle, R. W. (2002). Working Memory Capacity as Executive Attention. *Current Directions in Psychological Science*, *11*(1), 19–23. https://doi.org/10.1111/1467-8721.00160

Epshtein, B., Lifshitz, I., & Ullman, S. (2008). Image interpretation by a single bottom-up top-down cycle. *Proceedings of the National Academy of Sciences*, *105*(38), 14298–14303. https://doi.org/10.1073/pnas.0800968105

Ettinger, U., Meyhöfer, I., Mehta, M. A., Kumari, V., Corr, P. J., Williams, S. C., & Perkins, A. M. (2018). Effects of lorazepam on saccadic eye movements: The role of sex, task characteristics and baseline traits. *Journal of Psychopharmacology*, *32*(6), 678–690. https://doi.org/10.1177/0269881118772450

Evans, K. K., & Baddeley, A. (2018). Intention, attention and long-term memory for visual scenes: It all depends on the scenes. *Cognition*, *180*, 24–37. https://doi.org/10.1016/j.cognition.2018.06.022

Faraone, S. V. (2000). Attention Deficit Hyperactivity Disorder in Adults. *CURRENT DIRECTIONS IN PSYCHOLOGICAL SCIENCE*, *9*(1), 4.

Figueiredo, T., Lima, G., Erthal, P., Martins, R., Corção, P., Leonel, M., Ayrão, V., Fortes, D., & Mattos, P. (2020). Mind-wandering, depression, anxiety and ADHD: Disentangling the relationship. *Psychiatry Research*, *285*, 112798. https://doi.org/10.1016/j.psychres.2020.112798

Flechsenhar, A., Rösler, L., & Gamer, M. (2018). Attentional Selection of Social Features Persists Despite Restricted Bottom-Up Information and Affects Temporal Viewing Dynamics. *Scientific Reports*, *8*(1), 12555. https://doi.org/10.1038/s41598-018-30736-8

Fletcher-Watson, S., Findlay, J. M., Leekam, S. R., & Benson, V. (2008). Rapid Detection of Person Information in a Naturalistic Scene. *Perception*, *37*(4), 571–583. https://doi.org/10.1068/p5705

Forster, S., & Lavie, N. (2009). Harnessing the wandering mind: The role of perceptual load. *Cognition*, *111*(3), 345–355. https://doi.org/10.1016/j.cognition.2009.02.006

Forster, S., & Lavie, N. (2016). Establishing the Attention-Distractibility Trait. *Psychological Science*, *27*(2), 203–212. https://doi.org/10.1177/0956797615617761

Forster, S., Robertson, D. J., Jennings, A., Asherson, P., & Lavie, N. (2014). Plugging the attention deficit: Perceptual load counters increased distraction in ADHD. *Neuropsychology*, *28*(1), 91–97. https://doi.org/10.1037/neu0000020

Fosco, W. D., Kofler, M. J., Groves, N. B., Chan, E. S. M., & Raiker, J. S. (2020). Which 'Working' Components of Working Memory aren't Working in Youth with ADHD? *Journal of Abnormal Child Psychology*, *48*(5), 647–660. https://doi.org/10.1007/s10802-020-00621-y

Foulsham, T., Cheng, J. T., Tracy, J. L., Henrich, J., & Kingstone, A. (2010). Gaze allocation in a dynamic situation: Effects of social status and speaking. *Cognition*, *117*(3), 319–331. https://doi.org/10.1016/j.cognition.2010.09.003

Foulsham, T., Farley, J., & Kingstone, A. (2013). Mind wandering in sentence reading: Decoupling the link between mind and eye. *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, *67*(1), 51–59. https://doi.org/10.1037/a0030217

Foulsham, T., Frost, E., & Sage, L. (2018). Stable individual differences predict eye movements to the left, but not handedness or line bisection. *Vision Research*, *144*, 38–46. https://doi.org/10.1016/j.visres.2018.02.002

Foulsham, T., Gray, A., Nasiopoulos, E., & Kingstone, A. (2013). Leftward biases in picture scanning and line bisection: A gaze-contingent window study. *Vision Research*, *78*, 14–25. https://doi.org/10.1016/j.visres.2012.12.001

Foulsham, T., & Kingstone, A. (2010). Asymmetries in the direction of saccades during perception of scenes and fractals: Effects of image type and image features. *Vision Research*, *50*(8), 779–795. https://doi.org/10.1016/j.visres.2010.01.019

Foulsham, T., & Kingstone, A. (2017). Are fixations in static natural scenes a useful predictor of attention in the real world? *Canadian Journal of Experimental Psychology/Revue Canadienne de Psychologie Expérimentale*, *71*(2), 172–181. https://doi.org/10.1037/cep0000125

Foulsham, T., & Sanderson, L. A. (2013). *Look who's talking? Sound changes gaze behaviour in a dynamic social scene*. 24.

Foulsham, T., & Underwood, G. (2007). How Does the Purpose of Inspection Influence the Potency of Visual Salience in Scene Perception? *Perception*, *36*(8), 1123–1138. https://doi.org/10.1068/p5659

Foulsham, T., & Underwood, G. (2008). What can saliency models predict about eye movements? Spatial and sequential aspects of fixations during encoding and recognition. *Journal of Vision*, *8*(2), 6. https://doi.org/10.1167/8.2.6

Foulsham, T., & Underwood, G. (2009). Short article: Does conspicuity enhance distraction? Saliency and eye landing position when searching for objects. *Quarterly Journal of Experimental Psychology*, *62*(6), 1088–1098. https://doi.org/10.1080/17470210802602433

Franklin, M. S., Mrazek, M. D., Anderson, C. L., Johnston, C., Smallwood, J., Kingstone, A., & Schooler, J. W. (2007). Tracking Distraction. *Journal of Attention Disorders*, 12.

Freeth, M., Foulsham, T., & Kingstone, A. (2013). What Affects Social Attention? Social Presence, Eye Contact and Autistic Traits. *PLoS ONE*, *8*(1), e53286. https://doi.org/10.1371/journal.pone.0053286

Friedrichs, B., Igl, W., Larsson, H., & Larsson, J.-O. (2012). Coexisting Psychiatric Problems and Stressful Life Events in Adults With Symptoms of ADHD—A Large Swedish Population-Based Study of Twins. *Journal of Attention Disorders*, *16*(1), 13–22. https://doi.org/10.1177/1087054710376909

Gau, S. S.-F., & Shang, C.-Y. (2010). Executive functions as endophenotypes in ADHD: Evidence from the Cambridge Neuropsychological Test Battery (CANTAB): Executive functions as ADHD endophenotypes. *Journal of Child Psychology and Psychiatry*, *51*(7), 838–849. https://doi.org/10.1111/j.1469-7610.2010.02215.x

Gazzaley, A., Rissman, J., & D'Esposito, M. (2004). Functional connectivity during working memory maintenance. *Cognitive, Affective, & Behavioral Neuroscience*, *4*(4), 580–599. https://doi.org/10.3758/CABN.4.4.580

Geier, C. F., Garver, K., Terwilliger, R., & Luna, B. (2009). Development of Working Memory Maintenance. *Journal of Neurophysiology*, *101*(1), 84–99. https://doi.org/10.1152/jn.90562.2008

Gilbert, C. D., & Li, W. (2013). Top-down influences on visual processing. *Nature Reviews Neuroscience*, *14*(5), 350–363. https://doi.org/10.1038/nrn3476

Godijn, R., & Theeuwes, J. (2002). Programming of endogenous and exogenous saccades: Evidence for a competitive integration model. *Journal of Experimental Psychology: Human Perception and Performance*, *28*(5), 1039–1054. https://doi.org/10.1037/0096-1523.28.5.1039

Gray, S., Woltering, S., Mawjee, K., & Tannock, R. (2014). The Adult ADHD Self-Report Scale (ASRS): Utility in college students with attention-deficit/hyperactivity disorder. *PeerJ*, *2*, e324. https://doi.org/10.7717/peerj.324

Guo, K. (2007). Initial fixation placement in face images is driven by top–down guidance. *Experimental Brain Research*, *181*(4), 673–677. https://doi.org/10.1007/s00221-007-1038-5

Guo, K., Meints, K., Hall, C., Hall, S., & Mills, D. (2009). Left gaze bias in humans, rhesus monkeys and domestic dogs. *Animal Cognition*, *12*(3), 409–418. https://doi.org/10.1007/s10071-008-0199-3

Guo, K., Robertson, R. G., Mahmoodi, S., Tadmor, Y., & Young, M. P. (2003). How do monkeys view faces? A study of eye movements. *Experimental Brain Research*, *150*(3), 363–374. https://doi.org/10.1007/s00221-003-1429-1

Hakim, N., deBettencourt, M. T., Awh, E., & Vogel, E. K. (2020). Attention fluctuations impact ongoing maintenance of information in working memory. *Psychonomic Bulletin & Review*, *27*(6), 1269–1278. https://doi.org/10.3758/s13423-020-01790-z

Hancock, P. J. B., Bruce, V., & Burton, A. M. (2000). Recognition of unfamiliar faces. *Trends in Cognitive Sciences*, *4*(9), 330–337. https://doi.org/10.1016/S1364-6613(00)01519-9

Hansen, B. H., Oerbeck, B., Skirbekk, B., Petrovski, B. É., & Kristensen, H. (2018). Neurodevelopmental disorders: Prevalence and comorbidity in children referred to mental health services. *Nordic Journal of Psychiatry*, *72*(4), 285–291. https://doi.org/10.1080/08039488.2018.1444087

Hayes, T. R., & Henderson, J. M. (2017). Scan patterns during real-world scene viewing predict individual differences in cognitive capacity. *Journal of Vision*, *17*(5), 23. https://doi.org/10.1167/17.5.23

Hayes, T. R., & Henderson, J. M. (2018). Scan patterns during scene viewing predict individual differences in clinical traits in a normative sample. *PLOS ONE*, *13*(5), e0196654. https://doi.org/10.1371/journal.pone.0196654

Hayward, D. A., & Ristic, J. (2013). The uniqueness of social attention revisited: Working memory load interferes with endogenous but not social orienting. *Experimental Brain Research*, *231*(4), 405–414. https://doi.org/10.1007/s00221-013-3705-z

Helfer, B., Boxhoorn, S., Songa, J., Steel, C., Maltezos, S., & Asherson, P. (2021). Emotion recognition and mind wandering in adults with attention deficit hyperactivity disorder or autism spectrum disorder. *Journal of Psychiatric Research*, *134*, 89–96. https://doi.org/10.1016/j.jpsychires.2020.12.059

Henderson, J. M. (1992). *Visual attention and eye movement control during reading and picture viewing. In Eye movements and visual cognition*. 260–283.

Herman, J. P., Arcizet, F., & Krauzlis, R. J. (2020). Attention-related modulation of caudate neurons depends on superior colliculus activity. *ELife*, *9*, e53998. https://doi.org/10.7554/eLife.53998

Herrmann, M. J., Schreppel, T., Biehl, S. C., Jacob, C., Heine, M., Boreatti-Hümmer, A., Mühlberger, A., & Fallgatter, A. J. (2009). Emotional deficits in adult ADHD patients: An ERP study. *Social Cognitive and Affective Neuroscience*, *4*(4), 340–345. https://doi.org/10.1093/scan/nsp033

Ho, S., Foulsham, T., & Kingstone, A. (2015). Speaking and Listening with the Eyes: Gaze Signaling during Dyadic Interactions. *PLOS ONE*, *10*(8), e0136905. https://doi.org/10.1371/journal.pone.0136905

Hobbiss, M. H., Fairnie, J., Jafari, K., & Lavie, N. (2019). Attention, mindwandering, and mood. *Consciousness and Cognition*, *72*, 1–18. https://doi.org/10.1016/j.concog.2019.04.007

Hopfinger, J. B., Buonocore, M. H., & Mangun, G. R. (2000). The neural mechanisms of top-down attentional control. *Nature Neuroscience*, *3*(3), 284–291. https://doi.org/10.1038/72999

Itti, L., & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision Research*, *40*(10–12), 1489–1506. https://doi.org/10.1016/S0042-6989(99)00163-7

Itti, L., & Koch, C. (2001). *Computational Modelling of Visual Attention*. 11.

Jackson, M. C., & Raymond, J. E. (2008). Familiarity enhances visual working memory for faces. *Journal of Experimental Psychology: Human Perception and Performance*, *34*(3), 556–568. https://doi.org/10.1037/0096-1523.34.3.556

Jang, J., Matson, J. L., Williams, L. W., Tureck, K., Goldin, R. L., & Cervantes, P. E. (2013). Rates of comorbid symptoms in children with ASD, ADHD, and comorbid ASD and

ADHD. *Research in Developmental Disabilities*, *34*(8), 2369–2378. https://doi.org/10.1016/j.ridd.2013.04.021

Jang, K.-M., Kim, M.-S., & Kim, D.-W. (2020). The Dynamic Properties of a Brain Network During Spatial Working Memory Tasks in College Students With ADHD Traits. *Frontiers in Human Neuroscience*, *14*, 580813. https://doi.org/10.3389/fnhum.2020.580813

Jonkman, L. M., Markus, C. Rob., Franklin, M. S., & van Dalfsen, J. H. (2017). Mind wandering during attention performance: Effects of ADHD-inattention symptomatology, negative mood, ruminative response style and working memory capacity. *PLOS ONE*, *12*(7), e0181213. https://doi.org/10.1371/journal.pone.0181213

Kasper, L. J., Alderson, R. M., & Hudec, K. L. (2012). Moderators of working memory deficits in children with attention-deficit/hyperactivity disorder (ADHD): A meta-analytic review. *Clinical Psychology Review*, *32*(7), 605–617. https://doi.org/10.1016/j.cpr.2012.07.001

Katsuki, F., & Constantinidis, C. (2014). Bottom-Up and Top-Down Attention: Different Processes and Overlapping Neural Systems. *The Neuroscientist*, *20*(5), 509–521. https://doi.org/10.1177/1073858413514136

Kessler, R. C., Adler, L., Ames, M., Demler, O., Faraone, S., Hiripi, E., Howes, M. J., Jin, R., Secnik, K., Spencer, T., Ustun, T. B., & Walters, E. E. (2005). The World Health Organization adult ADHD self-report scale (ASRS): A short screening scale for use in the general population. *Psychological Medicine*, *35*(2), 245–256. https://doi.org/10.1017/S0033291704002892

Kim, S., Liu, Z., Glizer, D., Tannock, R., & Woltering, S. (2014). Adult ADHD and working memory: Neural evidence of impaired encoding. *Clinical Neurophysiology*, *125*(8), 1596–1603. https://doi.org/10.1016/j.clinph.2013.12.094

Kleberg, J. L., Frick, M. A., & Brocki, K. C. (2020). Increased pupil dilation to happy faces in children with hyperactive/impulsive symptoms of ADHD. *Development and Psychopathology*, 1–11. https://doi.org/10.1017/S0954579420000036

Klin, A., Jones, W., Schultz, R., Volkmar, F., & Cohen, D. (2002). Visual Fixation Patterns During Viewing of Naturalistic Social Situations as Predictors of Social Competence in Individuals With Autism. *ARCH GEN PSYCHIATRY*, *59*, 8.

Konstantinou, N., Beal, E., King, J.-R., & Lavie, N. (2014). Working memory load and distraction: Dissociable effects of visual maintenance and cognitive control. *Attention, Perception, & Psychophysics*, *76*(7), 1985–1997. https://doi.org/10.3758/s13414-014-0742-z

Konstantinou, N., & Lavie, N. (2013). Dissociable roles of different types of working memory load in visual detection. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(4), 919–924. https://doi.org/10.1037/a0033037

Konstantinou, N., & Lavie, N. (2020). Effects of visual short-term memory load and attentional demand on the contrast response function. *Journal of Vision*, *20*(10), 6. https://doi.org/10.1167/jov.20.10.6

Laidlaw, K. E. W., Foulsham, T., Kuhn, G., & Kingstone, A. (2011). Potential social interactions are important to social attention. *Proceedings of the National Academy of Sciences*, *108*(14), 5548–5553. https://doi.org/10.1073/pnas.1017022108

Laidlaw, K. E. W., & Kingstone, A. (2017). Fixations to the eyes aids in facial encoding; covertly attending to the eyes does not. *Acta Psychologica*, *173*, 55–65. https://doi.org/10.1016/j.actpsy.2016.11.009

Laidlaw, K. E. W., Risko, E. F., & Kingstone, A. (2012). A new look at social attention: Orienting to the eyes is not (entirely) under volitional control. *Journal of*

*Experimental Psychology: Human Perception and Performance*, *38*(5), 1132–1143. https://doi.org/10.1037/a0027075

Lakens, D., & Caldwell, A. R. (2021). Simulation-Based Power Analysis for Factorial Analysis of Variance Designs. *Advances in Methods and Practices in Psychological Science*, *4*(1), 2515245920951503.

Lamme, V. A. F., & Roelfsema, P. R. (2000). The distinct modes of vision offered by feedforward and recurrent processing. *Trends in Neurosciences*, *23*(11), 571–579. https://doi.org/10.1016/S0166-2236(00)01657-X

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, *21*(3), 451–468. https://doi.org/10.1037/0096-1523.21.3.451

Lavie, N. (2005). Distracted and confused?: Selective attention under load. *Trends in Cognitive Sciences*, *9*(2), 75–82. https://doi.org/10.1016/j.tics.2004.12.004

Lavie, N. (2010). Attention, Distraction, and Cognitive Control Under Load. *Current Directions in Psychological Science*, *19*(3), 143–148. https://doi.org/10.1177/0963721410370295

Lavie, N., Beck, D. M., & Konstantinou, N. (2014). Blinded by the load: Attention, awareness and the role of perceptual load. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *369*(1641), 20130205. https://doi.org/10.1098/rstb.2013.0205

Lavie, N., & De Fockert, J. (2005). The role of working memory in attentional capture. *Psychonomic Bulletin & Review*, *12*(4), 669–674. https://doi.org/10.3758/BF03196756

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load Theory of Selective Attention and Cognitive Control. *Journal of Experimental Psychology: General*, *133*(3), 339–354. https://doi.org/10.1037/0096-3445.133.3.339

Lavie, N., & Tsal, Y. (1994). Perceptual load as a major determinant of the locus of selection in visual attention. *Perception & Psychophysics*, *56*(2), 183–197. https://doi.org/10.3758/BF03213897

Lecerf, T., & de Ribaupierre, A. (2005). Recognition in a visuospatial memory task: The effect of presentation. *European Journal of Cognitive Psychology*, *17*(1), 47–75. https://doi.org/10.1080/09541440340000420

Lin, L., & Xu, C. (2020). Arcsine-based transformations for meta-analysis of proportions: Pros, cons, and alternatives. *Health Science Reports*, *3*(3), e178.

Lorenc, E. S., Mallett, R., & Lewis-Peacock, J. A. (2021). Distraction in Visual Working Memory: Resistance is Not Futile. *Trends in Cognitive Sciences*, *25*(3), 228–239. https://doi.org/10.1016/j.tics.2020.12.004

Luck, S. J., Gaspelin, N., Folk, C. L., Remington, R. W., & Theeuwes, J. (2021). Progress toward resolving the attentional capture debate. *Visual Cognition*, *29*(1), 1-21.

Mallett, R., Mummaneni, A., & Lewis-Peacock, J. A. (2020). Distraction biases working memory for faces. *Psychonomic Bulletin & Review*, *27*(2), 350–356. https://doi.org/10.3758/s13423-019-01707-5

Marotta, A., Casagrande, M., Rosa, C., Maccari, L., Berloco, B., & Pasini, A. (2014). Impaired reflexive orienting to social cues in attention deficit hyperactivity disorder. *European Child & Adolescent Psychiatry*, *23*(8), 649–657. https://doi.org/10.1007/s00787-013-0505-8

Martinez Cedillo, A. P., Dent, K., & Foulsham, T. (2021). *Do cognitive load and ADHD traits affect the tendency to prioritise social information in scenes?* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/pqx45

McFarland, R., Roebuck, H., Yan, Y., Majolo, B., Li, W., & Guo, K. (2013). Social Interactions through the Eyes of Macaques and Humans. *PLoS ONE*, *8*(2), e56437. https://doi.org/10.1371/journal.pone.0056437

McNab, F., Leroux, G., Strand, F., Thorell, L., Bergman, S., & Klingberg, T. (2008). Common and unique components of inhibition and working memory: An fMRI, within-subjects investigation. *Neuropsychologia*, *46*(11), 2668–2682. https://doi.org/10.1016/j.neuropsychologia.2008.04.023

Miller, B. T., & D'Esposito, M. (2005). Searching for "the Top" in Top-Down Control. *Neuron*, *48*(4), 535–538. https://doi.org/10.1016/j.neuron.2005.11.002

Mowlem, F. D., Agnew-Blais, J., Pingault, J.-B., & Asherson, P. (2019). Evaluating a scale of excessive mind wandering among males and females with and without attention-deficit/hyperactivity disorder from a population sample. *Scientific Reports*, *9*(1), 3071. https://doi.org/10.1038/s41598-019-39227-w

Mowlem, F. D., Skirrow, C., Reid, P., Maltezos, S., Nijjar, S. K., Merwood, A., Barker, E., Cooper, R., Kuntsi, J., & Asherson, P. (2019). Validation of the Mind Excessively Wandering Scale and the Relationship of Mind Wandering to Impairment in Adult ADHD. *Journal of Attention Disorders*, 11.

Nigg, J. T. (2001). Is ADHD a disinhibitory disorder? *Psychological Bulletin*, *127*(5), 571–598. https://doi.org/10.1037/0033-2909.127.5.571

Oh, S.-H., & Kim, M.-S. (2004). The role of spatial working memory in visual search efficiency. *Psychonomic Bulletin & Review*, *11*(2), 275–281. https://doi.org/10.3758/BF03196570

Olivers, C. N. L., Meijer, F., & Theeuwes, J. (2006). Feature-based memory-driven attentional capture: Visual working memory content affects visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *32*(5), 1243–1265. https://doi.org/10.1037/0096-1523.32.5.1243

Oosterlaan, J., Logan, G. D., & Sergeant, J. A. (1998). Response Inhibition in AD/HD, CD, Comorbid AD/HD+CD, Anxious, and Control Children: A Meta-analysis of Studies with the Stop Task. *Journal of Child Psychology and Psychiatry*, *39*(3), 411–425. https://doi.org/10.1111/1469-7610.00336

Ortega, R., López, V., Carrasco, X., Escobar, M. J., García, A. M., Parra, M. A., & Aboitiz, F. (2020). Neurocognitive mechanisms underlying working memory encoding and retrieval in Attention-Deficit/Hyperactivity Disorder. *Scientific Reports*, *10*(1), 7771. https://doi.org/10.1038/s41598-020-64678-x

Panagiotidi, M., Overton, P., & Stafford, T. (2017). Increased microsaccade rate in individuals with ADHD traits. *Journal of Eye Movement Research*, *10*(1). https://doi.org/10.16910/10.1.6

Parkhurst, D., Law, K., & Niebur, E. (2002). Modeling the role of salience in the allocation of overt visual attention. *Vision Research*, *42*(1), 107–123. https://doi.org/10.1016/S0042-6989(01)00250-4

Pecchinenda, A., & Petrucci, M. (2016). Emotion Unchained: Facial Expression Modulates Gaze Cueing under Cognitive Load. *PLOS ONE*, *11*(12), e0168111. https://doi.org/10.1371/journal.pone.0168111

Poole, B. J., & Kane, M. J. (2009). Working-memory capacity predicts the executive control of visual search among distractors: The influences of sustained and selective attention. *Quarterly Journal of Experimental Psychology*, *62*(7), 1430–1454. https://doi.org/10.1080/17470210802479329

Posner, M. I., Rafal, R. D., Choate, L. S., & Vaughan, J. (1985). Inhibition of return: Neural basis and function. *Cognitive Neuropsychology*, *2*(3), 211–228. https://doi.org/10.1080/02643298508252866

Proskovec, A. L., Wiesman, A. I., Heinrichs-Graham, E., & Wilson, T. W. (2019). Load effects on spatial working memory performance are linked to distributed alpha and beta oscillations. *Human Brain Mapping*, hbm.24625. https://doi.org/10.1002/hbm.24625

Raz, S., & Dan, O. (2015). Altered event-related potentials in adults with ADHD during emotional faces processing. *Clinical Neurophysiology*, *126*(3), 514–523. https://doi.org/10.1016/j.clinph.2014.06.023

Riesenhuber, M., & Poggio, T. (1999). Hierarchical models of object recognition in cortex. *Nature Neuroscience*, *2*(11), 1019–1025. https://doi.org/10.1038/14819

Risko, E. F., Anderson, N., Sarwal, A., Engelhardt, M., & Kingstone, A. (2012). Everyday Attention: Variation in Mind Wandering and Memory in a Lecture: Mind wandering. *Applied Cognitive Psychology*, *26*(2), 234–242. https://doi.org/10.1002/acp.1814

Ristic, J., & Kingstone, A. (2005). Taking control of reflexive social attention. *Cognition*, *94*(3), B55–B65. https://doi.org/10.1016/j.cognition.2004.04.005

Ritchie, K. L., Kramer, R. S. S., Mileva, M., Sandford, A., & Burton, A. M. (2021). Multiple-image arrays in face matching tasks with and without memory. *Cognition*, *211*, 104632. https://doi.org/10.1016/j.cognition.2021.104632

Rossion, B., Torfs, K., Jacques, C., & Liu-Shuang, J. (2015). Fast periodic presentation of natural images reveals a robust face-selective electrophysiological response in the human brain. *Journal of Vision*, *15*(1), 18–18. https://doi.org/10.1167/15.1.18

Rudkin, S. J., Pearson, D. G., & Logie, R. H. (2007). Executive processes in visual and spatial working memory tasks. *Quarterly Journal of Experimental Psychology*, *60*(1), 79–100. https://doi.org/10.1080/17470210600587976

Scheerer, N. E., Birmingham, E., Boucher, T. Q., & Iarocci, G. (2021). Attention capture by trains and faces in children with and without autism spectrum disorder. *PLOS ONE*, 28.

Seernani, D., Damania, K., Ioannou, C., Penkalla, N., Hill, H., Foulsham, T., Kingstone, A., Anderson, N., Boccignone, G., Bender, S., Smyrnis, N., Biscaldi, M., Ebner-Priemer, U., & Klein, C. (n.d.). Visual search in ADHD, ASD and ASD + ADHD: overlapping or dissociating disorders? *Adolescent Psychiatry*, 14.

Seernani, D., Damania, K., Ioannou, C., Penkalla, N., Hill, H., Foulsham, T., Kingstone, A., Anderson, N., Boccignone, G., Bender, S., Smyrnis, N., Biscaldi, M., Ebner-Priemer, U., & Klein, C. (2021). Visual search in ADHD, ASD and ASD + ADHD: overlapping or dissociating disorders? *Adolescent Psychiatry*, 14.

Seli, P., Risko, E. F., Purdon, C., & Smilek, D. (2017). Intrusive thoughts: Linking spontaneous mind wandering and OCD symptomatology. *Psychological Research*, *81*(2), 392–398. https://doi.org/10.1007/s00426-016-0756-3

Seli, P., Smallwood, J., Cheyne, J. A., & Smilek, D. (2015). On the relation of mind wandering and ADHD symptomatology. *Psychonomic Bulletin & Review*, *22*(3), 629–636. https://doi.org/10.3758/s13423-014-0793-0

Sergeant, J. A., Geurts, H., Huijbregts, S., Scheres, A., & Oosterlaan, J. (2003). The top and the bottom of ADHD: A neuropsychological perspective. *Neuroscience & Biobehavioral Reviews*, *27*(7), 583–592. https://doi.org/10.1016/j.neubiorev.2003.08.004

Serrano, V. J., Owens, J. S., & Hallowell, B. (2018). Where Children With ADHD Direct Visual Attention During Emotion Knowledge Tasks: Relationships to Accuracy, Response Time, and ADHD Symptoms. *Journal of Attention Disorders*, *22*(8), 752–763. https://doi.org/10.1177/1087054715593632

Shoham, R., Sonuga-Barke, E., Yaniv, I., & Pollak, Y. (2020). What Drives Risky Behavior in ADHD: Insensitivity to its Risk or Fascination with its Potential Benefits? *Journal of Attention Disorders*, 108705472095082. https://doi.org/10.1177/1087054720950820

Smallwood, J., & Schooler, J. W. (2015). The Science of Mind Wandering: Empirically Navigating the Stream of Consciousness. *Annual Review of Psychology*, *66*(1), 487–518. https://doi.org/10.1146/annurev-psych-010814-015331

Smyth, M. M., Hay, D. C., Hitch, G. J., & Horton, N. J. (2005). Serial Position Memory in the Visual—Spatial Domain: Reconstructing Sequences of Unfamiliar Faces. *The Quarterly Journal of Experimental Psychology Section A*, *58*(5), 909–930. https://doi.org/10.1080/02724980443000412

Sonuga-Barke, E. J. S., Dalen, L., Daley, D., & Remington, B. (2002). Are Planning, Working Memory, and Inhibition Associated With Individual Differences in Preschool ADHD Symptoms? *Developmental Neuropsychology*, *21*(3), 255–272. https://doi.org/10.1207/S15326942DN2103_3

Sonuga-Barke, E. J. S., Taylor, E., Sembi, S., & Smith, J. (1992). Hyperactivity and Delay Aversion?I. The Effect of Delay on Choice. *Journal of Child Psychology and Psychiatry*, *33*(2), 387–398. https://doi.org/10.1111/j.1469-7610.1992.tb00874.x

Sreenivasan, K. K., & D'Esposito, M. (2019). The what, where and how of delay activity. *Nature Reviews Neuroscience*, *20*(8), 466–481. https://doi.org/10.1038/s41583-019-0176-7

Sugase, Y., Yamane, S., Ueno, S., & Kawano, K. (1999). Global and fine information coded by single neurons in the temporal visual cortex. *Nature*, *400*(6747), 869–873. https://doi.org/10.1038/23703

Theeuwes, J. (1991). Cross-dimensional perceptual selectivity. *Perception & Psychophysics*, *50*(2), 184–193. https://doi.org/10.3758/BF03212219

Theeuwes, J. (2010). Top–down and bottom–up control of visual selection. *Acta Psychologica*, *135*(2), 77–99. https://doi.org/10.1016/j.actpsy.2010.02.006

Theeuwes, J. (2018). Visual Selection: Usually Fast and Automatic; Seldom Slow and Volitional. *Journal of Cognition*, *1*(1), 29. https://doi.org/10.5334/joc.13

Theeuwes, J., de Vries, G.-J., & Godijn, R. (2003). Attentional and oculomotor capture with static singletons. *Perception & Psychophysics*, *65*(5), 735–746. https://doi.org/10.3758/BF03194810

Theeuwes, J., & Failing, M. (2020). *Attentional Selection: Top-Down, Bottom-Up and History-Based Biases*. Cambridge University Press.

Tomasello, M. (2008). *Origins of human communication*. MIT Press.

Treisman, A. M. (1980). *A Feature-Integration Theory of Attention*. 40.

Tye, C., Mercure, E., Ashwood, K. L., Azadi, B., Asherson, P., Johnson, M. H., Bolton, P., & McLoughlin, G. (2013). Neurophysiological responses to faces and gaze direction differentiate children with ASD, ADHD and ASD + ADHD. *Developmental Cognitive Neuroscience*, *5*, 71–85. https://doi.org/10.1016/j.dcn.2013.01.001

Underwood, G., Foulsham, T., van Loon, E., Humphreys, L., & Bloyce, J. (2006). Eye movements during scene inspection: A test of the saliency map hypothesis. *European Journal of Cognitive Psychology*, *18*(3), 321–342. https://doi.org/10.1080/09541440500236661

Van der Stigchel, S., & Hollingworth, A. (2018). Visuospatial Working Memory as a Fundamental Component of the Eye Movement System. *Current Directions in Psychological Science*, *27*(2), 136–143. https://doi.org/10.1177/0963721417741710

Van Dillen, L. F., & Derks, B. (2012). Working memory load reduces facilitated processing of threatening faces: An ERP study. *Emotion*, *12*(6), 1340–1349. https://doi.org/10.1037/a0028624

van Ewijk, H., Heslenfeld, D. J., Luman, M., Rommelse, N. N., Hartman, C. A., Hoekstra, P., Franke, B., Buitelaar, J. K., & Oosterlaan, J. (2014). Visuospatial Working Memory in ADHD Patients, Unaffected Siblings, and Healthy Controls. *Journal of Attention Disorders*, *18*(4), 369–378. https://doi.org/10.1177/1087054713482582

van Zoest, W., & Donk, M. (2005). The effects of salience on saccadic target selection. *Visual Cognition*, *12*(2), 353–375. https://doi.org/10.1080/13506280444000229

van Zoest, W., Donk, M., & Theeuwes, J. (2004). The Role of Stimulus-Driven and Goal-Driven Control in Saccadic Visual Selection. *Journal of Experimental Psychology: Human Perception and Performance*, *30*(4), 746–759. https://doi.org/10.1037/0096-1523.30.4.749

VanRullen, R. (2007). The power of the feed-forward sweep. *Advances in Cognitive Psychology*, *3*(1), 167–176. https://doi.org/10.2478/v10053-008-0022-3

Vo, M. L.-H., Smith, T. J., Mital, P. K., & Henderson, J. M. (2012). Do the eyes really have it? Dynamic allocation of attention when viewing moving faces. *Journal of Vision*, *12*(13), 3–3. https://doi.org/10.1167/12.13.3

Vogel, E. K., Woodman, G. F., & Luck, S. J. (2001). Storage of features, conjunctions, and objects in visual working memory. *Journal of Experimental Psychology: Human Perception and Performance*, *27*(1), 92–114. https://doi.org/10.1037/0096-1523.27.1.92

Walther, D., & Koch, C. (2006). Modeling attention to salient proto-objects. *Neural Networks*, *19*(9), 1395–1407. https://doi.org/10.1016/j.neunet.2006.10.001

Warton, D. I., Blanchet, F. G., O'Hara, R. B., Ovaskainen, O., Taskinen, S., Walker, S. C., & Hui, F. K. (2015). So many variables: joint modeling in community ecology. *Trends in Ecology & Evolution*, *30*(12), 766-779.

Westerberg, H., & Klingberg, T. (2007). Changes in cortical activity after training of working memory—A single-subject analysis. *Physiology & Behavior*, *92*(1–2), 186–192. https://doi.org/10.1016/j.physbeh.2007.05.041

Wigham, S., Rodgers, J., Berney, T., Le Couteur, A., Ingham, B., & Parr, J. R. (2019). Psychometric properties of questionnaires and diagnostic measures for autism spectrum disorders in adults: A systematic review. *Autism*, *23*(2), 287–305. https://doi.org/10.1177/1362361317748245

Wilterson, A. I., Nastase, S. A., Bio, B. J., Guterstam, A., & Graziano, M. S. A. (2021). Attention, awareness, and the right temporoparietal junction. *Proceedings of the National Academy of Sciences*, *118*(25), e2026099118. https://doi.org/10.1073/pnas.2026099118

Woltering, S., Gu, C., Liu, Z.-X., & Tannock, R. (2021). Visuospatial Working Memory Capacity in the Brain After Working Memory Training in College Students With ADHD: A Randomized Controlled Trial. *Journal of Attention Disorders*, *25*(7), 1010–1020. https://doi.org/10.1177/1087054719879487

Young, S., González, R. A., Mutch, L., Mallet-Lambert, I., O'Rourke, L., Hickey, N., Asherson, P., & Gudjonsson, G. H. (2016). Diagnostic accuracy of a brief screening tool for attention deficit hyperactivity disorder in UK prison inmates. *Psychological Medicine*, *46*(7), 1449–1458. https://doi.org/10.1017/S0033291716000039

Zhang, H., Anderson, N. C., & Miller, K. (2020a). *Mind-wandering during Scene Perception: On the Role of Meaning and Salience* [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/9fc2u

Zhang, H., Anderson, N. C., & Miller, K. F. (2020b). *Refixation Patterns of Mind-wandering during Real-world Scene Perception*. 22.

Zhang, W., & Luck, S. J. (2009). Sudden Death and Gradual Decay in Visual Working Memory. *Psychological Science*, *20*(4), 423–428. https://doi.org/10.1111/j.1467-9280.2009.02322.x

Zickerick, B., Thönes, S., Kobald, S. O., Wascher, E., Schneider, D., & Küper, K. (2020). Differential Effects of Interruptions and Distractions on Working Memory Processes in an ERP Study. *Frontiers in Human Neuroscience*, *14*, 84. https://doi.org/10.3389/fnhum.2020.00084