The Effect of Perceived Perceptual Grouping on the Spatiotemporal Profile of Attention During Reaches and Saccades

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Abstract

Attention influences perception of stimuli as well as mediated action. This allows us to interact with complex visual environments. Additionally, hand-eye movements are linked and occur in high levels of synchrony in daily tasks. Existing research examining attentional facilitation during these behaviours has mostly utilised simple paradigms that are not representative of naturalistic settings. This study bridges the existing literary gap by documenting the effect of perceptual grouping on attentional facilitation during hand-eye movements in a complex visual scene. Participants completed a saccade and reach task in two experimental conditions. Eye and hand movements were made to one of two targets after a probe (contrast increment) was displayed in an array of seven constantly present distractors. Attentional facilitation was quantified by correct probe identification. Surprisingly, perceptual grouping did not influence attentional facilitation, though probe location did. Results indicate higher perceptual performance at locations that were not directly in the eye-hand movement trajectory, which was unexpected. One location was completely overlooked, which is consistent with previous findings. The findings suggest a possible difference in attentional facilitation between simple and complex scenes and reaffirm the need for future studies to utilise more naturalistic spatial layouts when examining attentional facilitation.

Declaration

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11th November, 2019

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The Effect of Perceived Perceptual Grouping on the Spatiotemporal Profile of Attention During Reaches and Saccades

Background

Vision is an important sense that provides normally sighted individuals with the necessary information to navigate their surroundings and to complete daily tasks. People make rapid eye movements, referred to as saccades, to change where they are looking approximately three times per second (Land & Furneaux, 1997; Rolfs & Carrasco, 2012). But 'seeing' is not a passive process. Reality does not simply impress itself onto our senses. We must interpret sensory input to create psychologically meaningful constructs of the world. This process is accomplished through our perception, which makes perception a vital component of vision.

Attention can also significantly impact perception. When perceiving the world, people orientate themselves and focus on parts of the environment that are particularly relevant to their immediate goals and needs. Most natural behaviours rely on visually mediated action – we look at and attend to things to interact with them in some way. Ballard et al. (1992) and Hayhoe, Bensinger, and Ballard (1998) demonstrated that eye-hand movements are closely coupled, spatially and temporally, in artificial tasks that required assembling coloured blocks. Their research indicated that saccades generally preceded hand movements with a fraction of a second, which makes it useful and necessary to research saccades and reaches both together and independently. For example, it has been well documented that top-down selective attention can guide saccades (Carrasco, 2011; Kowler, 2011; Land, 2009). But how is attention spread across the visual field?

Research into this topic (Stewart & Ma-Wyatt, 2015, 2017) has provided some insights regarding how attention is organised when performing simple movements within a simple visual scene. Notably, while there is much existing literature on saccades and hand movements, most studies have utilized paradigms of simple movements and visual scenes (see Kowler, 2011 for review). But in real life, goal directed movements often involve complex visual scenes. People must regularly interact with cluttered environments that present numerous locations where visual targets can be discovered (Deubel & Schneider, 1996; Jonikaitis & Deubel, 2011; Kowler, Anderson, Dosher, & Blaser, 1995). Therefore, while these investigations are certainly useful, it is unclear how they will translate to more complex scenes.

Making sense of cluttered scenes also necessitates visual parsing, that is, segregating the visual scene into distinct, complete, objects (Reich & Amedi, 2015). How the visual system organises the visual scene into objects and surfaces, though, is still unclear (Verghese & Stone, 1996). Nevertheless, some studies propose that segmentation may affect the spatial profile of attention. For example Verghese and stone (1996, 1997) has demonstrated that participants were better able to integrate information from multiple stimuli across space if they perceived the stimuli as a single ‘patch’ compared to segmented ‘multiple patches’. Similarly, Ghahghaei and Verghese (2017) investigated the effects of a two-textured background on the spatiotemporal profile of attention around a cued target. Their results indicated attentional facilitation was higher at the border of two orthogonal, concentric, circles compared to a uniformly textured circle. This suggests that observers may have grouped the inner-texture along with the target.

Experimental research aims to relate to and predict behaviour in the real world. The present study thus intends to extend existing literature (e.g. Ouyang, 2018) to try and address the aforementioned discrepancy between simple and more true to life scenes during a reach and saccade task. This will be accomplished by utilising a visual array that more closely simulates a complex visual environment. Furthermore, this study attempts to also extend existing literature on visual object segmentation (e.g. Ghahghaei & Verghese, 2017; Verghese & Stone, 1996, 1997) by investigating whether the perceptual grouping of space has any effect on the way attention is distributed across time and space. The study will simulate the ‘objectification’ of space by incorporating a ‘cookie’ shape around multiple targets.

Vision, Saccades, and Movement

Eye movements. Saccades have been studied extensively to understand how people are gathering information for a task, or how that information is being used. Much research has focused on activities that require the oculomotor system to focus saccades close to the points where information is being received including reading (e.g. Geyer, 1967; Liversedge et al., 2016); music reading (e.g. Goolsby, 1994; Land & Furneaux, 1997); and driving (e.g. Land & Lee, 1994). Unlike these repetitive tasks, Land, Mennie, and Rusted (1999) and Hayhoe, Shrivastava, Mruczek, and Pelz (2003) attempted to further understand how eyes are used in more dynamic tasks. The researchers used video cameras to track participants’ saccades and hand movements while making tea and sandwiches respectively. After dividing saccades and hand movements into sections and comparing them to the overarching goal of the activity, the researchers concluded that the pattern of fixations were closely aligned with objects that were about to be manipulated by the hands. A key point that has emerged in these studies is that saccades typically precede motor actions by a fraction of a second. That is, the eye-movement system is gathering information to successfully perform motor actions. It also often makes anticipatory saccades based on both the information gathered during previous fixations, and subsets of schemas or motivations based on the task being completed. Contrary to the impression generated by lab studies where saccades are treated as ‘responses to stimuli’, in the real world they are proactive, not reactive.

Eye and hand movements as a behavioural unit. Eye and hand moments make up a common behavioural unit when people make goal directed movements to interact with their environment. In support of this correlation, Abrams, Meyer, and Kornblum (1990) demonstrated that the temporal difference between saccades and hand movements were close to zero while eye-hand latencies ranged from 60-100ms. That is, when reaching for a lone target, participants generated hand and eye movements at roughly the same time though the eyes reached the target between 60-100ms before the hand. This close eye-hand movement association can be neurologically explained by the role of the parietal lobe in reaching- and grasping-movements during saccades and in managing hand-eye coordination (Baldauf, Cui, & Andersen, 2008; Land et al., 1999; Land, 2009). This is partly due to the fact that the parietal cortex is a region of convergence for multiple sensory modalities and a large part of its activity is dedicated to the orientating and maintenance of spatial attention as well as generating and controlling saccades (e.g. Moore, 2006; Ptak & Müri, 2013).

Visual and motor mechanisms. Understanding how eye and hand movements facilitate environmental interaction requires understanding the mechanisms behind their initiation. Saccades and hand movements tend to occur in high levels of synchrony. Consequently, hand movements tend to be more accurate with visual guidance. We can conclude that this is likely the case because the same visual information is used to program both the saccade and the reach. Prior to a saccade, a target is localised in the periphery. The visual system then sends information about the target, which is used to program and initiate the saccade (e.g. Abrams et al., 1990; Gegenfurtner & Franz, 2007; Ma-Wyatt & McKee, 2006). In a simple isolated reach task with a single target, Abrams et al. (1990) demonstrated that saccades and reaches are only programed after the target has been located in the periphery. However, natural environments may present several targets that are potentially relevant for action. So how are targets prioritised over time and how does one decides to reach or saccade to a location?

Some research addresses this question by proposing the importance of a salience map (Koch & Ullman, 1987). That is, features of objects in the environment (such as colour, intensity, and motion) are computed in parallel by early visual areas. These maps are combined into a single saliency map representing conspicuities across the visual scene, and compete for attentional allocation. Areas with the highest salience draw attention first (e.g. Itti & Koch, 2000). While this model may be useful for certain tasks (such as a visual search), other research (e.g. Hayhoe et al., 2003) has demonstrated that salience may be less important in goal-directed tasks as attention is only allocated to task-relevant regions. Instead, Land (2009) suggests that there are four distinct systems in the brain involved in the visual control of action. The gaze-, motor-, and visual-systems are responsible for locating, acting upon, and supplying information about objects respectively. The schema-system provides overall control of these systems through internal representation of tasks (scripts) ensuring coherent action.

But how do these systems work together to facilitate integrated movement? For example, grasping an object requires us to firstly determine it’s exact retinal position. This information must then be translated from a retinal-centred coordination to a real world coordination, which is independent of our eyes, heads, and bodies. Only then can a motor program be devised that will eventually lead to grasping the object in its proper position (Gegenfurtner & Franz, 2007). While this serial scheme of sensori-motor processing seems intuitive, a large body of evidence suggests two parallel visual streams – one for mediating conscious perception of objects, and one for guiding actions (Goodale & Milner, 1992; Goodale & Westwood, 2004; Milner & Goodale, 1995). They are the so-called ventral (what) and dorsal (where) streams (Goodale & Milner, 1992). The ventral 'perceptual' stream encodes objects' spatial properties and computes a detailed map from visual input (which can then be used for cognitive operations) while the dorsal 'action' stream transforms visual information into coordinated motor planning and execution.

Attention

The visual system provides the brain with a lot of information, but we do not consciously process everything we see. This is exemplified in phenomena such as change- and inattentional-blindness (Simons & Chabris, 1999). Attention refers to the process of focusing conscious awareness, which is generally influenced by both external (environmental stimuli) and internal (goals and motives) factors (Burton, Westen, & Kowalski, 2011). Attention underpins both the cognitive and behavioural aspects of any goal-directed movement - if we want to interact with objects we need to be able to focus on relevant stimuli while disregarding irrelevant stimuli. We generally distinguish between two main types of visual attention: Feature-based attention (FBA) and Spatial attention (Carrasco, 2011).

FBA is concerned with salience of objects in the visual field (such as colour, orientation, and motion). That is, attention can be drawn to objects whose characteristics make them stand out from the background. As the design of the present experiment involves uniform distractors and targets, FBA will not be discussed in further detail. Spatial attention is classified as goal-directed attention in vision and refers to the selection of specific areas in the visual field. It is thus referred to as selective attention. Attentional deployment can be either overt (attentional deployment accompanied by saccadic shifts) or covert (attention deployment in the periphery without accompanying saccadic shifts) (Carrasco, 2011). Furthermore, there are two systems of covert attention: sustained (which corresponds to our ability to consciously monitor in a given location) and transient (which corresponds to automatic, involuntary attentional deployment in response to sudden stimuli) (Pestilli & Carrasco, 2005).

Attentional resources. People are bombarded with complex layers of visual information on a daily basis, but the visual system cannot process it all at once. Due to the limited processing capacity of the human brain (Kahneman, 1973), the selection of information that is relevant to current behaviour and motivation is mediated by selective attention. Eriksen and James (1986) propose that there is a trade-off between the size of the region in the visual field being attended to and the level of detail (resolution) being processed. We can observe this trade-off in the deployment of different types of attention. Covert attention can be deployed over a wide range of the visual field (e.g. Carrasco, 2011; Kowler, 2011), but due to this spread, limited resources are dedicated to resolution. Consequently, very limited amounts of information about the target can be processed. Contrarily, overt attention (such as object identification) has a limited spatial spread. High attentional resources are dedicated to processing foveated objects or locations, which results in high-resolution vision (Baldauf & Deubel, 2009). The trade-off between sharp resolution and attentional spread has been demonstrated neurologically by Müller, Bartelt, Donner, Villringer, and Brandt (2003), who found that neural activity in visual areas of the brain corresponds to the size of the visual region being attended to.

Mechanisms of attention, saccades, and reaches. Spatial attention is an important driver of saccadic shifts to relevant locations in the visual field. Both overt and covert attentional shifts function as a means to prepare and execute saccades by determining target locations and guiding shifts in attention to them. But attention also significantly contributes to coordinated motor control, as it determines which objects in the visual field is to be used as targets to plan and guide movement (Jonikaitis & Deubel, 2011). It has also been established that coordinated motor actions suffer when not accompanied by a saccade. For example when studying the role of saccades on the accuracy of guided movement, Abrams et al. (1990) found that when constraints were placed on participants' eye movements, they made significantly more errors on a wrist rotation task compared to when they could saccade to the target area. The researchers concluded that these findings exemplify the importance of both retinal and extra-retinal information that the eyes provide in guided movements.

Based on these considerations, it is important then to also examine the association between saccades and high-resolution perceptual attention. Specifically the extent, if any, that objects can be attended to when a saccade is made to a different location. Kowler et al. (1995) addressed this question through a series of letter-recognition experiments. Participants fixated on a central fixation point surrounded by alphabetical letters. A given trial required saccading to a letters (target) that was cued, and reporting that letter. At the time of reporting, a second stimulus was presented at an un-cued location, and participants were asked to report it as well. When participants were informed to report on two target locations, but the location of the non-goal was unspecified, successful letter identification was only observed at the saccade goal. Kowler et al. (1995) concluded that saccades require a shift in attention and that perceptual attention cannot be present at non-target location. This is because the level of resolution needed for interpreting target information cannot be equally deployed over a wide area of the visual field during the execution of a saccade. In a similar experiment, Hoffman and Subramaniam (1995) explored the relationship between saccades and covert attention by asking participants to either saccade to a specific location while simultaneously detecting a target presented just prior to saccade onset; or to explicitly direct attention to one location while simultaneously saccading to another. Results revealed superior target detection at saccade locations, indicating that it is not possible to saccade in one direction while attending to another. These findings provide support for the non-independence of mechanisms underlying saccades and attentional shifts.

Spatiotemporal profile of selective attention.

We have thus far established that attention can be deployed overtly or covertly as well as in a sustained or transient way, but that saccades cannot be made without a simultaneous shift in attention. We can therefore not overtly attend to objects without attending to them, but we can do so covertly. We have also established that spatial attention enhances performance of visual processing in both the attended and neighbouring areas of that location. But how is attention deployed across time and space?

Research in this area has generally involved using probe-detection tasks with simple designs and single or few visual targets. For example, while examining attentional facilitation of covert attention while preparing sequences of manual pointing, Baldauf and Deubel (2009) found enhanced contrast sensitivity at the targets of the sequence. Their results are consistent with previous observations regarding pre-movement deployment of selective attention to relevant action-goals (e.g. Hayhoe et al., 2003; Land et al., 1999).

Similarly, Stewart and Ma-Wyatt (2015) mapped the spatiotemporal properties relative to reach for reaches, saccades, and reaches coupled with saccades. The researchers used a probe-detection task where targets were presented at various locations and at various times relative to cue onset. Consequently, the researchers suggested, while there may be similar preparation processes and pattern of cortical activation involved, there could still be different mechanisms involved in attentional activation for saccades and reaches.

Therefore, investigating the extent to which attentional facilitation differs between reaches and saccades can allow conjectures regarding how attentional resources may be shared between saccades and hand movements. Indeed, previous research in this field has suggested an increase in sensitivity (attentional facilitation) leading up to the deployment of a movement (e.g. Jonikaitis & Deubel, 2011; Rolfs & Carrasco, 2012), however, their paradigms have mostly utilised simple arrays to test attentional spread and saccades and hand movements. While these results are informative, it is not clear how they will translate to more naturalistic scenes.

One final component of understanding the spatio-temporal deployment of attention involves understanding the perceptual processes involved in visual processing. Top-down processing is clearly an important perceptual component and involves progression from the whole down to its elements. Such processing is clearly captured in the principles of Gestalt psychology, which attempts to explain our ability to maintain meaningful perceptions in a ‘chaotic’ world of stimuli. These grouping-principals and proximity laws aim to explain our innate and automating grouping of objects to form perceptual consistency (e.g. Desolneux, Moisan, & More, 2003). Based on these considerations, we might expect the spatiotemporal profile of attention to be influenced by how a spatial layout is perceived. That is, we may expect to see a spatial layout being treated as a whole if it perceived as such as opposed to when it is perceived as being comprised of independent parts.

Rationale and Aims

The research examined thus far indicates that in naturalistic behaviour and in the lab, saccades and hand movements are closely linked during goal directed movements. However, the majority of research focussing on this link has utilised research paradigms comprising simple scenes and movements, which are unrepresentative of more complex visual scenes present in real life environments. It has also been suggested that, while saccades and hand movements may be linked since they involve similar preparation processes and cortical activation, there may still be separate underlying mechanisms involved in attentional activation of saccades and reaches (Hoffman & Subramaniam, 1995). It is thus of interest to see how saccades and reaches will be deployed in a complex visual scene.

Spatial attention is a selective process and is associated with top-down or goal-directed processes. It is evident from the aforementioned research that saccades cannot occur without a shift in overt attention. That is because saccading necessitates the foveation of certain areas in space and these areas necessarily occupies higher amounts of limited cognitive- and processing-resources. However, it is possible for a large area of the visual field to be overtly attended to without accompanying saccades. That is because objects can be attended to in the periphery without occupying much processing resources. Moreover, Gestalt laws (e.g. Desolneux et al., 2003) suggests that people innately and automatically group objects and research on segmentation (e.g. Ghahghaei & Verghese, 2017; Verghese & Stone, 1996, 1997) has indicated that spatial layout could play an important role in attentional facilitation. If people are able to covertly attend to areas in the visual field, and if areas of the visual field are attended to differently depending on features of the spatial layout, it can be argued that attentional might be deployed evenly and over an entire spatial layout if it were perceptually grouped as an object. Contrarily, if people do not perceive a spatial layout one object, one might expect there would be no reason for the whole layout to be attended to and therefore attentional shifts may only be accompanied by a saccade.

The present study intends to contribute to existing literature regarding the spatiotemporal profile of attention by using paradigms that are more representative of a naturalistic setting. The study aims to measure whether: 1) the spatiotemporal profile of attention is different when space is perceived as being an object, compared to whether it is perceived as ‘free space’ while performing saccades and reaches and 2) whether there is a difference in attentional spread between probe-locations in the spatial layout. To do so, the study takes reference from Ouyang (2018) in an attempt to create a direct model for comparison. Unlike Ouyang’s (2018) study, however, this study will only include a Saccade + Reach condition and utilize a fixed stimulus onset asynchrony (SOA) of 300ms. This decision was made based on previous research (Ghahghaei & Verghese, 2017; Ouyang, 2018; Stewart & Ma-Wyatt, 2015, 2017) demonstrating that the overall profile of attentional facilitation within saccade-only and reach-only conditions remain fairly consistent and are not significant; and that attentional facilitation and sensitivity peaks around probe onset times of approximately 300ms.

Based on previous research findings (e.g. Baldauf & Deubel, 2009; Stewart & Ma-Wyatt, 2015) and on theoretical research concerning perception (e.g. Ghahghaei & Verghese, 2017; Penev, 1996; Verghese & Stone, 1996, 1997), it is firstly hypothesised that the spatiotemporal profile of attention will differ on the basis of whether space is perceptually grouped as an object or as independent parts. Specifically, attentional facilitation will be greater in a spatial layout perceived as a single object compared to one perceived as being comprised of independent parts. Secondly it is hypothesised that there will be a difference in attentional facilitation regarding probe-location.

Specifically, probes-locations on eccentricities closer to the fixation point will receive more attentional benefits.

Method

Participants

Participants were recruited from the University of Adelaide and the general public through convenience and snowball sampling. Five participants completed the study, four of which were experienced psychophysical observers. The sample consisted of three males (M = 27 years, SD = 2.3) and two females (M = 25 years, SD = 4.2). One participant spoke a home language other than English (Mandarin), however all were fluent English speakers. Four participants were right-handed, as determined by the Edinburg handed inventory (Oldfield, 1971). Participation was voluntary and no compensation was given for taking part. All participants had normal or corrected to normal vision and no motor deficits.

Experimental design

The experimental design was a novel paradigm, which aimed to measure the distribution of attention during a saccade and reach task. The study’s experimental conditions took reference from previous work by Stewart and Ma-Wyatt (2015) and Ouyang (2018), who examined the spatiotemporal profiles of attentional facilitation for reaches and saccades. This experimental design utilises the same visual array of multiple targets and probes used by Ouyang (2018) to be more representative of a naturalistic spatial layout. The study also takes reference from Rolfs and Carrasco (2012), who investigated the effects of saccades on visual performance and perceived contrasts, by presenting probes at predetermined threshold levels during a saccade + reach task.

The experiment was a repeated measures within subjects design - all participants completed all conditions. The experiment comprised three separate tasks. Participants firstly completed a preliminary baseline task that served to set individual contrast threshold levels for perceptual probes that would appear in subsequent tasks. Participants then completed two experimental conditions in a saccade + reach task to measure attentional facilitation across the visual field. Participants completed 12 blocks of data collection for the experimental conditions.

The experiment ran for approximately 2-hours on average. Participants typically completed the experiment in two sessions. In the first session, participants completed the baseline task. Participants then completed the experimental conditions in the second session. The two conditions were counterbalanced, across participants, with half completing condition 1 (cookie condition) first while half completed condition 2 (no-cookie condition) first.

Apparatus

An eye-tracker and a touch-screen monitor were used to record data during the experiment. The monitor was a 17-inch ELO touch-screen with a resolution of 1024x768 pixels and a screen refresh rate of 85Hz (Elo Touch Solutions Inc., Milpitas, CA, US). During the task, stimuli were presented on the monitor. Eye-movements and position were recorded using an EyeLink 1000 eye tracker (SR Research, Ottawa, ON, Canada). Eye position was sampled at 1000Hz with a spatial precision of 0.25° as per the manufacturer's specifications. The experiment was run using custom software written in MATLAB (MathWorks, Natick, MA) using the Psychophysics Toolbox (Brainard & Vision, 1997; Pelli & Vision, 1997) to control stimulus presentation and response collection. Prior to the experiment, a photometer was used to correct the monitor's non-linear gamma function to be linear.

Procedure

This study was approved by the University of Adelaide School of Psychology Human Ethics Committee (Appendix A). Prior to the experiment participants were provided with an experiment information sheet (Appendix B); consent form (Appendix C); Edinburg handedness inventory (Oldfield, 1971) (Appendix D); and participant information sheet (Appendix E). Participants were informed that they could withdraw from the study at any time without penalty. All participants consented to participation by signing the consent form. The experimenter explained the task requirements in detail with specific instructions for each task before commencing the experiment (Appendix F). Participants were also given the opportunity to ask questions prior to and after concluding the experiment. Participants then completed the baseline task and experimental conditions respectively.

The experiment was conducted in a dark, quiet room. Participants sat at a desk, where the experimental equipment was set up. The eye-tracker was mounted on the edge of the desk. The monitor was positioned 40 centimetres from the edge of the desk and raised on a wooden block to participants' eye-level. A mouse and keyboard were set up between the eye-tracker and monitor for use during experimental tasks. Participants sat at the desk with their heads resting on the eye-tracker's chinrest for the duration of experimental tasks. The experimenter was present in the room and conducted all tasks for the duration of the experiment.

Baseline. Participants completed this preliminary task to determine their contrast threshold sensitivity. An example of the task design can be seen in Figure 1. This task aimed to set the contrast value for the perceptual probe in the experimental conditions by measuring the contrast threshold for each participant for the three eccentricities of the probe locations. The task design comprised a black fixation point in the bottom-centre of the screen, and two grey targets to the left and right side of the screen equidistant from the fixation point at either 5°, 10°, or 15° eccentricities respectively. This was done to ensure that all three eccentricities were equally detectable (e.g. Pointer & Hess, 1989), as contrast sensitivity scales as a function of eccentricity. The central fixation point was 0.25° in diameter and 80% Michelson contrast from the background. The targets were 0.75° in diameter and 80% contrast from the background. A photometer measured the background luminance of the screen, fixation point and targets at 67.8 cd/m^2, 1.6 cd/m^2, and 39.3 cd/m^2 respectively.

Participants were required to maintain fixation on the fixation point before depressing the spacebar to start the trial. Upon depressing the spacebar, a tone sounded to signal the start of the trial and a probe appeared at the location being tested. The probe displayed as a dot and appeared with equal probability inside either one of the grey targets as a contrast increment. The probe was 0.2° in diameter and remained on screen for 0.1 seconds at a time. Participants reported the contrast increment by pressing either 1 or 3 on the number pad, depending on whether they saw the increment in the left or right target area respectively. Once a response was entered, a long tone sounded to indicate the end of the trial. Immediately after, another short tone sounded to indicate that the participant might begin the next trial whenever they were ready by depressing the spacebar. Using a QUEST paradigm set to 82% threshold level (Watson & Pelli, 1983), the luminance of subsequent probes underwent an increment if the previous response was incorrect, and a decrement if the response was correct.

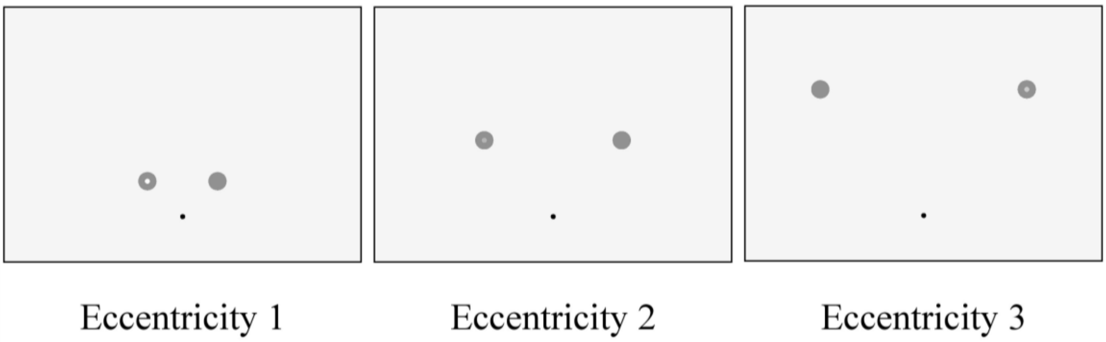


Figure 1. Diagram of baseline task for detecting contrast sensitivity. The spatial layout comprises the central fixation point (black dot at the bottom of the screen) and targets (grey circles). Targets are equidistant from the fixation point and placed at 5°, 10°, or 15° for eccentricities 1, 2, and 3 respectively. A perceptual probe appeared as a dot with equal probability at both the left and right targets. The probe would increase (example eccentricity 1) or decrease (example eccentricity 3) in luminance increments for incorrect or correct identification respectively in subsequent trials.

The baseline task took approximately 30 minutes to complete and was divided into three blocks per eccentricity for a total of 9 blocks. Each block included 40 trials for a total of 120 trials per eccentricity and 360 trials in total. Blocks took roughly 3 minutes each to complete. QUEST (Watson & Pelli, 1983) was used to estimate the 82% threshold sensitivity value, which was recorded after each block. A mean sensitivity value was then calculated for each eccentricity based on the results of the three blocks. These thresholds were consequently used as the contrast sensitivities of the probes, respective to their corresponding eccentricity, for each participant.

Saccade + reach task. This task comprised one central fixation point, two touch-targets, and seven probe-locations. An example of the task design can be seen in Figure 2. The central fixation point was 0.25° in diameter and 80% Michelson contrast from the background. The two touch-targets were located at 10° eccentricity from the centre, were 0.75° in diameter and 80% contrast from the background. The seven probe locations were 0.75° in diameter, 5° from their adjacent peers, and 25% contrast from the background. The probe, as a dot of contrast within the distractors, was 0.2° in diameter. In the cookie condition the ‘cookie’ shape was 36° in diameter and 12% contrast from the background. A photometer measured the background luminance of the screen, fixation point, touch-targets, and distractors at 67.8 cd/m^2, 1.6 cd/m^2, 39.3 cd/m^2, and 42.3 cd/m^2 respectively.

Theses specific probe locations were chosen so that the hand would not occlude them during any stage of the reach, and thus ensured that the reach did not affect performance on the task (Abrams et al., 1990).

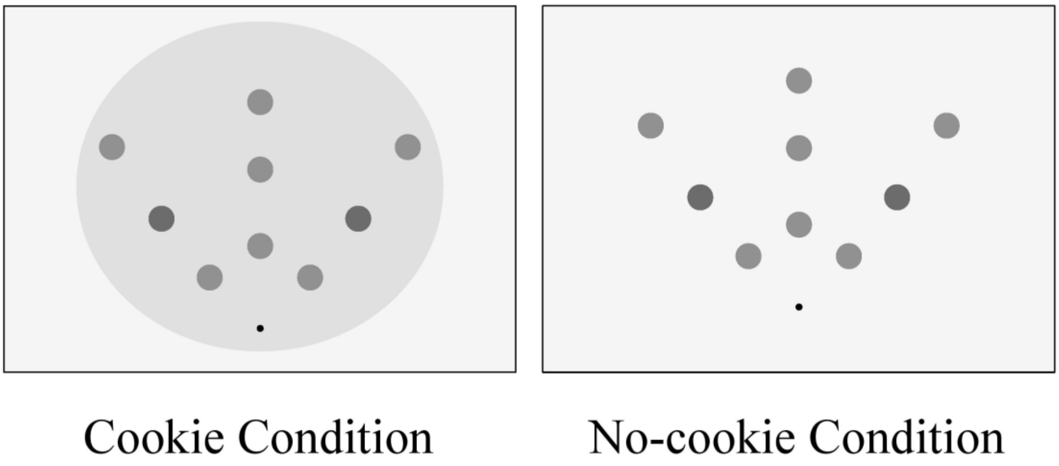


Figure 2. Diagram of experimental conditions. The spatial layout comprises the central fixation point (black dot at the bottom of the screen); the touch-targets (dark grey circles); and the seven distractors (light grey circles). The Cookie condition conceptualises perceptual grouping of the spatial layout by enclosing probe-locations in a ‘cookie’ shape (large light grey circle). The No-cookie condition illustrates the spatial layout as independent parts.

Both experimental conditions followed the same procedure with the only difference being in the spatial layout in the cookie condition. In the cookie condition the spatial layout is enclosed in a ‘cookie’ shape to conceptualise the space as an object.

This method of grouping was chosen as luminance and contrast has been demonstrated to be a strong perceptual grouping factor (Chen, Liu, & Fuh, 2005).

Each experimental condition comprised six blocks. In each of the six blocks, the probe appeared five times (5) at every possible probe location (7) for each reach side (left and right) (2) for a total of 70 trials per block and 420 trials per condition. Each block took between 3-5 minutes to complete. In general, participants completed each experimental task in two 3-block parts, with a break in between. At the start of each block, a brief calibration was carried out for the eye-tracker, after which the condition was run. An example of the experimental procedure can be seen in Figure 3.

At the start of each trial, a ‘home screen’ appeared displaying the spatial layout. Participants were required to fixate on the fixation point at the start of each trial. Participants rested their dominant hand on the mouse, which was affixed 40 cm from the screen and central to the screen and the participant’s body. Once participants were ready to start the trial, they were required to depress and hold the mouse-key. After the mouse-key had been depressed, there was a random delay of 0-500ms before cue onset on each trial. This was done to prevent learning effects/participants anticipating the cue.

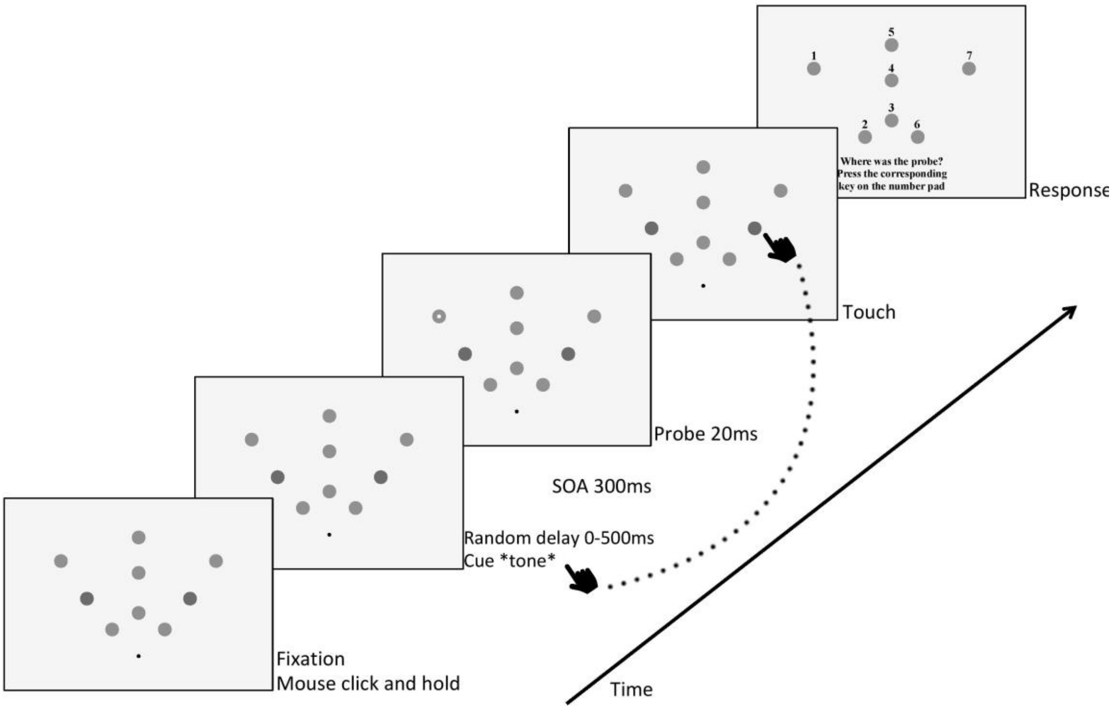


Figure 3. Diagrams of Saccade + Reach procedure for the no-cookie condition. After participants fixated and depressed the mouse, a cue sounded after a random delay of 0-500ms. The cue was either a high or low tone corresponding to the left and right targets respectively. After a stimulus onset asynchrony (SOA) of 300ms a perceptual probe (small light dot) appeared randomly at any of the seven probe locations. Participants released the mouse after the cue sounded and made a saccade and reach to either target. After the target was touched, a screen appeared with the text “Where was the probe? Press the corresponding key on the number pad”. The next trial was initiated after a response was recorded.

Once the cue sounded, the central fixation point disappeared, signalling participants to release the mouse-key and commence saccading and reaching to the target location as quickly as possible. The target location was determined by the tone of the cue – a high tone indicated the left target, while a low tone indicated the right target. After the cue sounded, a perceptual probe, which was 0.75° in diameter and remained on screen for 0.1 seconds at a time, was randomly presented at one of the seven probe locations after a stimulus onset asynchrony (SOA) of 300ms. After the target was touched, a new screen appeared displaying the seven probe locations, that were each assigned with a number, and text reading, “Where was the probe? Press the corresponding key on the number pad”. Participants then indicated where they believed the probe to have appeared by pressing the probe-location’s corresponding number on the keypad. After a number key had been pressed, the screen returned to the ‘home screen’ and participants depressed and held the mouse to begin the next trial.

Results

Data Exclusions

Data were collected and processed using MATLAB. Trials in which the saccade latency was less than 100ms were excluded in order to avoid anticipatory saccades that were not generated in response to the target (He & Kowler, 1989). Trials in which participants reached to the wrong target were also excluded. The percentage of trials retained for each participant for both experimental conditions are presented in Table 1.

Table 1

Percentage of trials retained for each participant in the two experimental conditions after applying the exclusion criteria

Participant	Cookie Condition	No-cookie Condition	Across Conditions
	Trials retained (%)		
P1	67	77	72
P2	61	66	63
P3	89	57	73
P4	64	53	59
P5	96	96	96

Note: Across conditions refers to the percentage of trials retained for the cookie and no-cookie conditions combined.

Conditions and Locations

The effects of attentional facilitation are represented by the mean proportion of correct responses made by participants for each probe location during a saccade and reach task. This was aggregated across a single block of trials for each participant. Data analyses were carried out using SPSS. A repeated measures analysis of variance (RM ANOVA) was run to examine the effects of the experimental conditions on attentional facilitation. All tests were conducted with an alpha significance level of 0.05, and degrees of freedom are reported according to the Greenhouse-Geisser correction, which is robust to violations of sphericity. The mean proportion of correct responses across all participants, for each probe location and for each experimental condition can be seen in Figure 4.

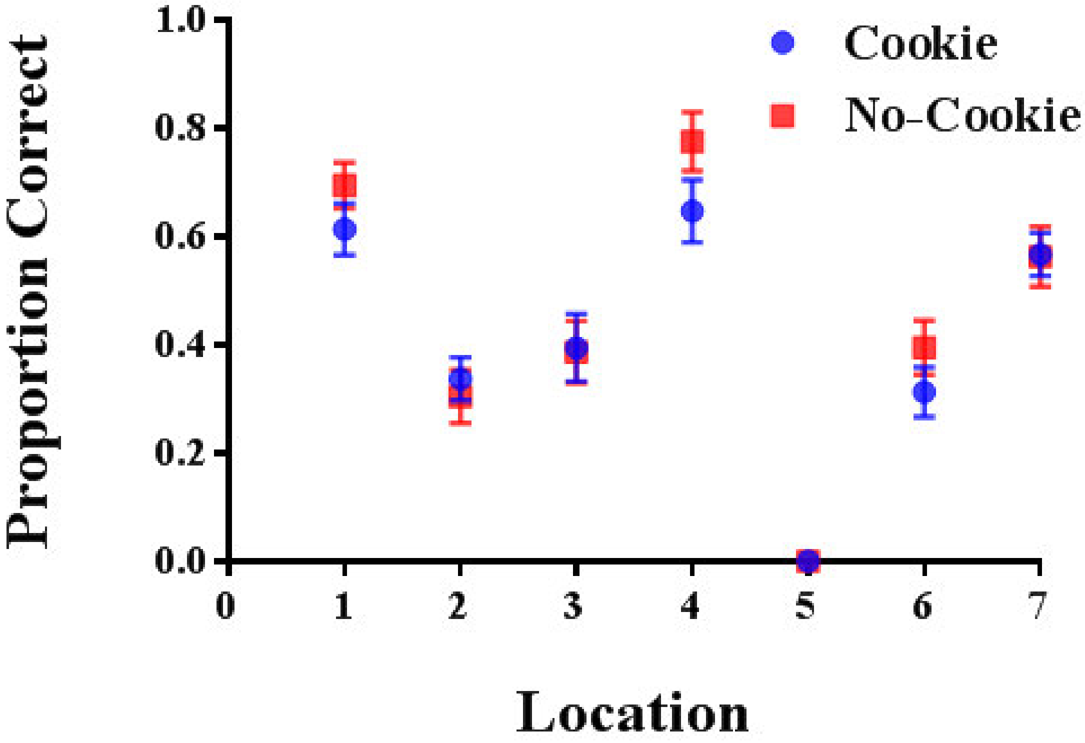


Figure 4. Mean correct response rates for probe location for the Cookie condition and No-cookie across all participants. Error bars are Standard Error of the Means (SEMs).

The first factor was experimental condition, with two levels (cookie condition and no-cookie condition). The second factor was probe location, with seven levels (locations 1 – 7). A Bonferroni correction was applied to correct the alpha-value for the number of comparisons made. The analysis showed that the main effect for condition on correct response rate was not significant, $F(1,28) = 1.56$, $p = 0.15$, $\eta_p^2 = 0.07$. That is, participants' rate of correct responses did not differ between cookie ($N = 211$, $M = 0.42$, $SEM = 0.03$) and the no-cookie ($N = 203$, $M = 0.45$, $SEM = 0.02$) conditions.

However, the main effect for location on correct response rate was significant, $F(6, 23) = 222.5$, $p < 0.001$, $\eta_p^2 = 0.98$. That is, participants' rate of correct responses did differ depending on the location the probe was presented at. Descriptive statistics for proportion of correct responses per probe location for both the cookie and no-cookie condition combined can be seen in Table 2.

Table 2

Descriptive statistics for proportion of correct responses per probe across conditions

Probe Location	*N*	*M*	*SEM*
1	60	0.66 (66%)	0.03
2	59	0.32 (32%)	0.03
3	59	0.39 (39%)	0.04
4	59	0.71 (71%)	0.04
5	59	0.00 (0%)	0.00
6	59	0.36 (36%)	0.03
7	59	0.57 (57%)	0.03

Note: N = Sample size, M = Mean, SEM = Standard Error of the Mean, Figures in parentheses are the percentages for mean correct responses per probe location.

The analysis indicates that probe-location had a significant effect on participants' rate of correct responses. The mean differences for the proportion of correct responses per probe location can be seen in Table 3.

Table 3

Mean differences and Standard Error of the Mean (SEM) for the proportion of correct responses for probe locations across experimental conditions

	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6	Loc 7
Loc 1	-						
Loc 2	0.33(0.05)**	-					
Loc 3	0.26(0.06)*	-0.07(0.04)	-				
Loc 4	-0.06(0.07)	-0.39(0.05)**	-0.32(0.04)**	-			
Loc 5	0.65(0.04)**	0.32(0.03)**	0.39(0.05)**	0.71(0.05)**	-		
Loc 6	0.30(0.05)**	-0.03(0.04)	0.04(0.05)	0.36(0.07)**	-0.35(0.04)**	-	
Loc 7	0.09(0.06)	-0.24(0.04)**	-0.18(0.06)	0.15(0.06)	-0.57(0.04)**	-0.21(0.04)**	-

Note: N = 59, Loc = Probe Location, Figures in parentheses are the Standard Error of the Mean, * = p <0.050, ** = p <0.001

Pairwise analyses indicate location 1 was significantly different to all locations except for location 4 and 7. Participants had significantly more correct responses in location 1 than locations 2, 3, 5, 6. Location 2 was significantly different to all locations except location 3 and 6. Participants had significantly less correct responses in location 2 than locations 4 and 7, and significantly more correct responses in location 2 than in location 5. Location 3 was significantly different to locations 4 and 5, but not to location 6 and 7. Participants had significantly more correct responses in location 4 than location 3, but significantly less correct responses in location 5 than location 3. Location 4 was significantly different to locations 5 and 6, but not to location 7. Participants had significantly less correct responses in locations 5 and 6 than location 4. Location 5 was significantly different to all other locations, in that participants had zero correct responses in this location. Lastly, location 6 was significantly different than location 7, with participants having significantly less correct responses in location 6.

Finally, the analysis shows no significant interaction between condition and probe location on correct response rate, $F(6, 23) = 1.88$, $p = 0.13$, $\eta_p^2 = 0.33$.

Grouped Locations

As condition did not have a significant impact on the proportion of correct responses, but location did, it was of interest to explore whether there would be any grouping-effects for probe location. Paired samples t-tests were conducted to explore whether probe locations closer to the central fixation point would experience any facilitation benefits compared with probe locations further away; and whether there is a difference in attentional facilitation to probe locations in the middle vertical row compared to the rest of the spatial layout. All tests were conducted with an alpha significance level of 0.05.

The analyses show that locations 2 and 6, when grouped together, are significantly different to locations 1 and 7 when grouped together. As a group, locations 2 and 6 had a smaller proportion of correct responses ($M = 0.50$, $SEM = 0.04$) than locations 1 and 7 as a group ($M = 0.94$, $SEM = 0.04$) and this difference was significant, $t(58) = -7.84$, $p <0.001$.

Probe locations on the third eccentricity of the spatial layout had a larger proportion of correct responses than probe locations on the first eccentricity. Analyses also show that, as a group, locations 3, 4, and 5 had a smaller proportion of correct responses ($M = 1.11$, $SEM = 0.07$) than locations 1, 2, 6, and 7 ($M = 1.48$, $SEM = 0.07$), and this difference was also significant $t(58) = -4.65$, $p < 0.001$. Locations in the middle vertical row had significantly less correct responses compared to other locations in the spatial layout.

As location 5 did not receive any correct responses at all, another paired samples t-test was conducted excluding it from the analysis. Results indicate that, as a group, locations 2, 3, and 6 had a smaller proportion of correct responses (*M* = 0.83, *SEM* = 0.07) compared to locations 1, 4, and 7 as a group (*M* = 1.56, *SEM* = 0.05) and these differences were significant, *t*(58) = -9.12, *p* < 0.001. Even with location 5 excluded, probe locations on eccentricities further away from the fixation point still had a significantly greater proportion of correct responses than locations closer to the fixation point.

Saccade and Reach Latencies, and Reach times

Descriptive statistics for the saccade latency, reach latency, and reach times for individual participants are presented in Table 4. Paired samples t-tests were conducted to examine whether experimental conditions had an impact on saccade and reach latency. All tests were conducted with an alpha significance level of 0.05. Analyses show no significant difference in participants' average saccade latency between the cookie (*N* = 30, *M* = 232.43, *SEM* = 12.93) and no-cookie condition (*N* = 29, *M* = 213.90, *SEM* = 8.86), *t*(29) = 1.52, *p* = 0.139. That is, while participants initiated eye movements slightly faster after cue presentation in the no-cookie condition, the difference was not significant.

There was no significant difference in participants' average reach latency between the cookie (*N* = 30, *M* = 684.70, *SEM* = 39.73) and the no-cookie (*N* = 30, *M* = 675.53, *SEM* = 51.36) condition, *t*(29) = 0.20, *p* = 0.840. That is, on average, participants tended to initiate hand movements at roughly the same time after cue presentation in both conditions.

Table 4

Descriptive statistics for individual participants' average saccade latency, reach latency, and reach time in milliseconds (ms) across experimental conditions

		Cookie Condition		No-cookie Condition	
		M	*SEM*	*M*	*SEM*
Saccade Latency	P1	154.50	3.17	199.33	9.54
	P2	228.67	7.94	201.00	4.46
	P3	287.38	25.83	195.00	9.15
	P4	189.17	6.48	179.33	4.10
	P5	302.43	29.89	299.33	9.69
Reach Latency	P1	785.00	52.77	418.67	5.99
	P2	444.33	4.46	528.00	13.38
	P3	500.33	14.38	441.82	19.68
	P4	859.83	28.88	876.17	21.81
	P5	834.00	104.74	1113.00	24.89
Reach Time	P1	285.17	21.56	407.00	9.84
	P2	370.83	7.15	426.33	15.11
	P3	687.83	56.68	579.33	23.04
	P4	193.17	20.16	159.83	21.73
	P5	433.00	47.00	185.17	18.89

Note: P = Participant, M = Mean, SEM = Standard Error of the Mean.

However, there was a significant difference between saccade latency and reach latency for both the cookie ($t[29] = -9.74$, $p < 0.001$), and no cookie ($t[29] = -9.95$, $p < 0.001$) conditions. That is, participants' saccade latencies were significantly faster than reach latencies across conditions.

Lastly, there was no significant difference in average reach time between the cookie ($N = 30$, $M = 394$, $SEM = 34.47$) and no-cookie ($N = 30$, $M = 351.53$, $SEM = 30.33$) condition, $t = 1.45$, $p = 0.159$.

Discussion

The present study was conducted with the aim to provide some insight as to what the spatiotemporal profile of selective attention would look like in a setting that is representative of a naturalistic environment during a saccade and reach task. The first aim of the study was to see whether attention would be facilitated differently based on whether such a spatial layout is perceptively grouped as an object or seen as free space. The second aim of the study was to establish whether attention would be facilitated differently in the spatial layout based on probe locations.

To follow up previous research in selective attention that have used simple designs with sparse visual arrays, this study has simulated a complex visual scene. Here, an experimental design comprising multiple targets and probes represented a more naturalistic visual array as might be encountered in daily life. These steps were taken to see how well previous findings in the literature could infer how people select objects from a visual scene that is filled with other, irrelevant stimuli. To simulate a spatial layout that can be perceived as an object, one of the experimental conditions had the probe locations enclosed in a ‘cookie’ shape. The other condition had no shape enclosing probe locations and represented a spatial layout comprising independent parts.

The first hypothesis of this study was that there would be differences in the observed profile of attention. Specifically, attentional facilitation would be greater in a spatial layout perceptually grouped as an object. The second hypothesis was that there would be differences in the observed profile of attention based on probe locations. Specifically, locations on eccentricities closer to the central fixation point would receive more attentional benefits compared to locations on eccentricities that were further away. These observations are operationalized by participants’ correct identification of the location of a contrast increment probe out of seven possible locations in each trial while performing a saccade and reach task. The results of the study indicate that these hypotheses are only partially supported, but not as expected.

Performance Relative to Experimental Condition

The hypothesis that attentional facilitation will be greater in a spatial layout that is perceived as on object compared to one perceived as free space was not supported. Contrary to expectations, on average, participants had a slightly higher proportion of correct responses in the no-cookie condition than the cookie condition. However, the differences in responses were not statistically significant (Table 3). These findings imply that, on average, participants had roughly the same number of correct responses across the two conditions, which implies that attentional facilitation was roughly equally spread across conditions.

The principal of Gestalt theory proposes that ‘grouping’ is the main process in visual perception (Desolneux et al., 2003). If different points in visual objects are perceived to share one or several characteristics (e.g. proximity, good continuation, colour consistency, etc.), they are perceptually grouped to form a new, larger visual object. In conjunction with these principles, Verghese and Stone (1996, 1997) have demonstrated that manipulating the way images are parsed or segregated influences how spatial information about that object is perceived. For example, in a fusion experiment, the researchers merged multiple stimulus patches in stages into a single patch. The closer the patch was to being fused into one patch, the better able participants could integrate information across the spatial layout. Contrarily, in a fission experiment, the researchers superimposed a cross over a single patch to segment the object into multiple quadrants. When the cross’ luminance was equal to that of the background, participants’ performance in a speed discrimination task decreased. The results showed that participants’ performance was best when they perceived the object as a whole and poorest when the quadrants were maximally separated. Interestingly, though, when the cross' luminance was darker than the background, it was perceived as an occluder rather than the patch being perceived as separate units. In this case, performance was the same as in the fusion experiment when the patch was perceived as a large whole. In a similar line, work by Ghahghaei and Verghese (2017) examined the spatial profile of sensitivity around a saccade target. The researchers measured attentional sensitivity with brief, dim, probe flashes presented at various distances around the saccade target. When the target was on a blank or uniformly textured background, sensitivity across space was highest at probe locations closest to the target. However, when the background was comprised of two textures, with the inner texture orthogonally orientated from the outer texture, attentional sensitivity was highest at the border of the two textures. This suggests that participants treated the target and inner texture as a whole object. These findings may be linked to research demonstrating that areas of the visual field can be attended to covertly without saccadic shifts (Carrasco, 2011).

Based on the aforementioned considerations, which the hypothesis in the current study was based on, the finding that the 'objectification' of space did not make a difference in attentional facilitation was surprising. Perhaps the findings may be explained in terms of the way the spatial layout was configured to objectify space. According to the Helmholtz Principle, an observed geometric structure is perceptually meaningful if its number of occurrences would be small in random situations. In this context, geometric structures are characterised as large deviations from randomness (Desolneux et al., 2003). While luminance and contrast has been shown to be very strong determinants of perceptual grouping (e.g. Chen et al., 2005), perhaps the 'cookie' shape was not perceived to be different or unique enough to be treated as a meaningful shape that would warrant treating the spatial layout as one object. Additionally, the current study does utilise a spatial layout with several uniform distractors and targets. While this layout might be more complex than previous studies, it is not clear at this stage how differences in attentional facilitation may be compared to studies with simpler layouts, but that have used textured backgrounds (e.g. Ghahghaei & Verghese, 2017; Verghese & Stone, 1996, 1997), instead of contrast differences.

Furthermore, perhaps there was no discernable difference in attentional facilitation across the conditions due to the task requirements. To investigate this possibility, it would be pertinent to consider the role of attention in perceptual grouping. Object-based theories of perception generally assume grouping is a process that happens early in the visual process and at a pre-attentive level (e.g. Moore & Egeth, 1997). This assumption is justified based on the grounds that grouping must occur early because the groups produced are required to achieve perceptual consistency – if attention must be directed at something, that thing must first exist. It was therefore assumed that participants would perceive the spatial layout as a grouped object and treat it as a single unit at a pre-attentive level. However, it must be considered that previous research has demonstrated that attention is only allocated to task-relevant regions in goal-directed tasks (Hayhoe et al., 2003). In their study, Hayhoe et al. (2003) examined patterns of eye-hand coordination and fixation during a naturalistic task (making a sandwich) and found that while participants generally only allocated attention to task relevant objects, planning coordinated eye-hand movements also required a representation of the visual scene that is built up over different fixations. In the current study, participants were not allowed to let their attention wonder across the spatial layout. They were required to fixate at the bottom of the screen and only saccade and reach to one of two target locations. Perhaps it is the case that the layout was not recognised or treated as an object because it was not directly part of the goal-directed task. That is, information from the whole layout was not needed to complete the task and therefore the layout as a whole was irrelevant.

Performance Relative to Probe Location

The hypothesis that there would be a difference in attentional facilitation based on probe location was partially supported, but not as expected. Contrary to expectations, probe locations on eccentricities further away from the central fixation point tended to have a higher proportion of correct responses compared to locations on eccentricities closer to the fixation, and these differences were significant. This implies that participants directed more attention to probe locations that were further away from the fixation point.

Probe location 4 had the highest proportion of correct responses, followed by locations 1, 7, 3, 6, and 2 respectively. An interesting finding is that there were no correct responses for location 5 at all, which implies that this location completely fell off the visual field in this spatial layout. This finding does seem to support previous work (Stewart & Ma-Wyatt, 2015, 2017) demonstrating attentional facilitation followed a similar pattern in a saccade + reach task and a saccade only task, suggesting that the saccade carries attention. In this study, location 5 was not intersecting the saccade path in any way. Thus, if saccade carries attention, it makes sense that it did not receive any attentional facilitation. However, if the saccade carries attention, it is equally interesting that probe location 4 received the highest number of correct responses, as it is not on the saccade path either. Perhaps this can be explained by the dual nature of the task. Participants were required to saccade and reach to a target location after hearing a cue. But this requires decision making on the participants' part – they needed to decide which direction to saccade and reach to first. Perhaps it is the case that participants were using prioritising strategies to cope with this part of the task. It might be possible that participants tended to saccade up and to the centre of the screen first (where probe location 4 was situated) and rest their gaze there for a split second while deciding to go either left or right, before actually saccading and reaching to the left or right. This explanation would be in line with previous research (e.g. Kowler, 2011) that demonstrates that factors such as perceived task goals and task difficulty can affect how attentional resources are allocated along the action path.

In this study it was hypothesised that probe locations closer to the central fixation point would receive more attentional benefits. This hypothesis was based on work demonstrating that saccade carries attention (Stewart & Ma-Wyatt, 2015, 2017) as well as on work demonstrating that patterns of eye fixations align with objects that are about to be manipulated (Hayhoe et al., 2003; Land et al., 1999). Probe locations 2 and 6 are in the line of movement the saccade has to travel to reach the target location. That is, a saccade has to pass over these locations to reach the touch targets. It is therefore surprising that these locations received significantly less attentional benefits than locations 1 and 7, which are not directly in line of the saccade movement. A possible explanation for this finding may due to the occlusion of perceptual probes by the hand. The probe locations in the spatial layout of the experimental design were specifically chosen to avoid this problem. However, it is possible that occlusion may still have occurred.

Performance Relative to Saccade and Reach Latency

The overall profile of attentional facilitation remains consistent between saccade and reach latencies. The study's findings show that eye saccade latency was slightly faster in the no-cookie condition. That is, participants' eye movements were slightly faster after cue presentation in the no-cookie condition, but not significantly so. There was almost no difference in reach latencies between conditions. Participants tended to initiate reach movements at roughly the same time and with the same speed after cue presentation in both conditions. However, there was a significant difference between saccade and reach latencies between conditions, with saccade latencies being significantly smaller. Based on the latency values (Table 2), it would appear that participants were completing saccades first before initiating reaches. These findings support previous single-target (e.g. Abrams et al., 1990; Stewart & Ma-Wyatt, 2017) and multiple-target studies (e.g. Ouyang, 2018) that demonstrates while eye and hand movements may be generated at roughly the same time when reaching for a lone target, the eyes tend to reach the target faster than the hand. These results also support studies that have demonstrated that eye movements contribute to guided motor control (e.g. Hayhoe et al., 2003; Jonikaitis & Deubel, 2011; Land et al., 1999).

Strengths and Limitations

One limitation of the present study may pertain to the spatial layout of the experimental design. This study utilised the same layout that was used by Ouyang (2018) in order to create a direct model for comparison. However, unlike Ouyang's (2018) study, this study aimed to measure the 'objectification' of space. Though measures were taken to conceptualise the spatial layout as an object as best as possible within the constraints of the current layout, these measures were purely theoretical. A potential solution to this problem may be to include a perceptual grouping task into the experimental design to systematically measure if and how well participants group elements within the spatial layout.

Another potential limitation is the variance in the number of retained trials for each participant. Participants completed six blocks for each experimental condition, with the aim of collecting 400 valid trials for each condition, which is comparative to previous experiments with similar aims and or task designs (e.g. Ouyang, 2018;

Stewart, 2016; Stewart & Ma-Wyatt, 2017). Unexpectedly, error rates were moderately high. This resulted in a high percentage of trial exclusions, with the exception of participant 5. More data was not collected to compensate for these exclusions due to time constraints, however doing so in the future may be beneficial for reducing variance between conditions.

The exclusion rate may nonetheless still give some insight into generalizability of task performance. That is, the high exclusion rates may in themselves imply that increasing the complexity of the visual scene can affect task performance in probe detection. Exclusion rates in this study is comparable to exclusion rates in the Saccade + Reach condition in Ouyang's (2018) study. This may imply that perceptual performance in experiments that utilise simple visual scenes may not be able to predict performance in more complex visual scenes. This consideration may further highlight the need for investigating the spatiotemporal profile of attention in more complex visual scenes.

Future Directions

Some improvements for the current experimental design could be for future studies to analyse probe locations and eccentricities separately to assess accuracy of equal visibility for all probe locations. This is especially relevant when considering that probe location 5, which was not captured in the baseline task, seems to have fallen completely out of the visual field. This will ensure that all probe locations are actually visible to participants when competing the task.

The current study may also be expanded upon by including different visual features, such as texture, in the spatial layout. Doing so would make the study comparable to pre-existing literature investigating the effects of texture on attentional facilitation, especially since texture has been shown to affect the spread of attentional facilitation during saccades (e.g. Ghahghaei & Verghese, 2017; Verghese & Stone, 1996, 1997). Examining the interaction of different visual features and how they affect the spatiotemporal profile of attention in a more complex spatial layout can be a further step in simulating a more realistic visual scene in a laboratory setting.

It is possible that the current study did not successfully ‘objectify’ the spatial layout in a meaningful manner either due to the ‘object’ not being novel enough, or due to the fact that task demands restricted attentional facilitation across the whole layout. Future studies can address his by perhaps configuring the spatial layout to include smaller ‘cookies’ that may be perceived as more novel against a uniform background. Alternatively, including movement sequences and saccades to multiple points across the layout will make it comparable to previous studies that have done so with simple layouts (e.g. Baldauf & Deubel, 2009).

Lastly, in addition to tracking eye movements, future studies may also track hand movements during reaching tasks. Doing so will allow researchers to ascertain whether there is any occlusion of the probe locations in more complex visual scenes. Tracking eye movements across the screen may also provide some insight as to whether participants are using any prioritising strategies while making task-related decisions, which will further facilitate understanding what factors may be influencing attentional facilitation.

Conclusion

In conclusion, the current study does not support the notion that the spatiotemporal profile of attention is affected by perceiving a complex spatial layout as an object while completing a saccade and reach task. However, the findings do indicate that probe location can influence perceptual performance. Specifically, the study indicated increased attentional facilitation at probe locations on eccentricities further away from the central fixation point compared to closer eccentricities. The greater discrepancy found between saccade and reach latencies compared to studies with simpler spatial layouts (Stewart & Ma-Wyatt, 2015, 2017) imply that the complexity of the visual scene affects perceptual performance. This highlights the importance of replicating naturalistic visual scenes in future explorations of selective attention.

References

Abrams, R. A., Meyer, D. E., & Kornblum, S. (1990). Eye-hand coordination: Oculomotor control in rapid aimed limb movements. *Journal of Experimental Psychology: Human Perception and Performance, 16*(2), 248.

Baldauf, D., Cui, H., & Andersen, R. A. (2008). The posterior parietal cortex encodes in parallel both goals for double-reach sequences. *Journal of Neuroscience, 28*(40), 10081-10089. doi: 10.1523/JNEUROSCI.3423-08.2008

Baldauf, D., & Deubel, H. (2009). Attentional Selection of Multiple Goal Positions Before Rapid Hand Movement Sequences: An event-related potential study. *Journal of Cognitive Neuroscience, 21*(1), 18-29. doi:10.1162/jocn.2008.21021

Ballard, D. H., Hayhoe, M. M., Li, F., Whitehead, S. D., Frisby, J. P., Taylor, J. G., & Fisher, R. B. (1992). Hand-Eye Coordination during Sequential Tasks [and Discussion]. *Philosophical Transactions of the Royal Society B: Biological Sciences, 337*(1281), 331-339. doi:10.1098/rstb.1992.0111

Brainard, D. H., & Vision, S. (1997). The psychophysics toolbox. *Spatial vision, 10*, 433-436.

Burton, L., Westen, D., & Kowalski, R. (2011). Consciousness and attention. In Consciousness, *Psychology* (E.d. 3) (pp188-193). Milton, Queensland: Wiley.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research, 51*(13), 1484-1525. doi:http://dx.doi.org/10.1016/j.visres.2011.04.012

Chen, H.-T., Liu, T.-L., & Fuh, C.-S. (2005). Tone Reproduction: A perspective from luminance-driven perceptual grouping. *International journal of computer vision, 65*(1/2), 73-96. doi:10.1007/s11263-005-3846-z

Desolneux, A., Moisan, L., & More, J. M. (2003). A grouping principle and four applications. *IEEE Transactions on Pattern Analysis and Machine Intelligence, 25*(4), 508-513. doi:10.1109/TPAMI.2003.1190576

Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research, 36*(12), 1827-1837. doi:https://doi.org/10.1016/0042-6989(95)00294-4

Eriksen, C. W., & James, J. D. S. (1986). Visual attention within and around the field of focal attention: A zoom lens model. *Perception & Psychophysics, 40*(4), 225-240. doi: 10.3758/bf03211502

Gegenfurtner, K. R., & Franz, V. H. (2007). A comparison of localization judgments and pointing precision. *Journal of vision, 7*(5), 11-11. doi: 10.1167/7.5.11

Geyer, J. J. (1967). Perceptual systems in reading--the prediction of a temporal eye-voice span constant. Paper. Retrieved from https://files.eric.ed.gov/fulltext/ED015086.pdf

Ghahghaei, S., & Verghese, P. (2017). Texture segmentation influences the spatial profile of presaccadic attention. *Journal of vision, 17*(2), 10. doi:10.1167/17.2.10

Goodale, M. A., & Milner, A. D. (1992). Separate visual pathways for perception and action. *Trends in neurosciences, 15*(1), 20-25. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/0166223692903448?via%3Dihub

Goodale, M. A., & Westwood, D. A. (2004). An evolving view of duplex vision: Separate but interacting cortical pathways for perception and action. *Current Opinion in Neurobiology, 14*(2), 203-211. doi: https://doi.org/10.1016/j.conb.2004.03.002

Goolsby, T. (1994). Profiles of Processing: Eye Movements During Sightreading. *Music Perception, 12*(1), 97-124. doi:10.2307/40285757

Hayhoe, M. M., Bensinger, D. G., & Ballard, D. H. (1998). Task constraints in visual working memory. *Vision Research, 38*(1), 125-137. doi: https://doi.org/10.1016/S0042-6989(97)00116-8

Hayhoe, M. M., Shrivastava, A., Mruczek, R., & Pelz, J. B. (2003). Visual memory and motor planning in a natural task. *Journal of vision, 3*(1), 49. doi:10.1167/3.1.6

He, P., & Kowler, E. (1989). The role of location probability in the programming of saccades: Implications for “center-of-gravity” tendencies. *Vision Research, 29*(9), 1165-1181. doi: https://doi.org/10.1016/0042-6989(89)90063-1

Hoffman, J., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception & Psychophysics, 57*(6), 787-795. doi:10.3758/BF03206794

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. doi: https://doi.org/10.1016/S0042-6989(99)00163-7

Jonikaitis, D., & Deubel, H. (2011). Independent allocation of attention to eye and hand targets in coordinated eye-hand movements. *Psychological Science, 22*(3), 339-347. doi: 10.1177/0956797610397666

Kahneman, D. (1973). *Attention and effort* (Vol. 1063): Citeseer. Retrieved from https://scholar.princeton.edu/sites/default/files/kahneman/files/attention_hi_quality.pdf

Koch, C., & Ullman, S. (1987). Shifts in selective visual attention: Towards the underlying neural circuitry. In *Matters of intelligence* (pp. 115-141): Springer. doi: https://doi.org/10.1007/978-94-009-3833-5_5

Kowler, E. (2011). Eye movements: the past 25 years. *Vision Research, 51*(13), 1457-1483. doi: https://doi.org/10.1016/j.visres.2010.12.014

Kowler, E., Anderson, E., Dosher, B., & Blaser, E. (1995). The role of attention in the programming of saccades. *Vision Research, 35*(13), 1897-1916. doi: https://doi.org/10.1016/0042-6989(94)00279-U

Land, M., Mennie, N., & Rusted, J. (1999). The roles of vision and eye movements in the control of activities of daily living. *Perception, 28*(11), 1311-1328. doi: 10.1068/p2935

Land, M. F. (2009). Vision, eye movements, and natural behavior. *Visual neuroscience, 26*(1), 51-62. doi: 10.1017/S0952523808080899

Land, M. F., & Furneaux, S. (1997). The knowledge base of the oculomotor system. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 352*(1358), 1231-1239. doi: 10.1098/rstb.1997.0105

Land, M. F., & Lee, D. N. (1994). Where we look when we steer. *Nature, 369*(6483), 742. doi: 10.1038/369742a0

Liversedge, S. P., Drieghe, D., Li, X., Yan, G., Bai, X., & Hyönä, J. (2016). Universality in eye movements and reading: A trilingual investigation. *Cognition: International Journal of Cognitive Science*, *147*(1-20). doi: https://doi.org/10.1016/j.cognition.2015.10.013

Ma-Wyatt, A., & McKee, S. P. (2006). Initial visual information determines endpoint precision for rapid pointing. *Vision Research, 46*(28), 4675-4683. doi: https://doi.org/10.1016/j.visres.2006.08.009

Milner, A. D., & Goodale, M. (1995). *The visual brain in action*. Oxford

New York: Oxford University Press.

Moore, C. M., & Egeth, H. (1997). Perception Without Attention: Evidence of Grouping Under Conditions of Inattention. *Journal of Experimental Psychology: Human Perception and Performance, 23*(2), 339-352. doi:10.1037/0096-1523.23.2.339

Moore, T. (2006). The neurobiology of visual attention: finding sources. *Current Opinion in Neurobiology, 16*(2), 159-165. doi:10.1016/j.conb.2006.03.009

Müller, N. G., Bartelt, O. A., Donner, T. H., Villringer, A., & Brandt, S. A. (2003). A physiological correlate of the “zoom lens” of visual attention. *Journal of Neuroscience, 23*(9), 3561-3565. doi: 10.1523/JNEUROSCI.23-09-03561.2003

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*(1), 97-113. doi: https://doi.org/10.1016/0028-3932(71) 90067-4

Ouyang, Y. (2018). *Attentional Facilitation During Reaches and Saccades in a Cluttered Setting.* Honours undergraduate thesis, The University of Adelaide, Adelaide, Australia.

Pelli, D. G., & Vision, S. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial vision, 10*, 437-442. doi: https://doi.org/10.1163/156856897X00366

Penev, S. P. (1996). Local feature analysis: A general statistical theory for object representation. *Network: Computation in Neural Systems, 7*(3), 477-500. doi:10.1088/0954-898X_7_3_002

Pestilli, F., & Carrasco, M. (2005). Attention enhances contrast sensitivity at cued and impairs it at uncued locations. *Vision Research, 45*(14), 1867-1875. doi:https://doi.org/10.1016/j.visres.2005.01.019

Pointer, J. S., & Hess, R. F. (1989). The contrast sensitivity gradient across the human visual field: With emphasis on the low spatial frequency range. *Vision Research, 29*(9), 1133-1151. doi:10.1016/0042-6989(89)90061-8

Ptak, R., & Müri, R. (2013). The parietal cortex and saccade planning: Lessons from human lesion studies. *Frontiers in human neuroscience, 7*, 254. doi: 10.3389/fnhum.2013.00254

Reich, L., & Amedi, A. (2015). 'Visual' parsing can be taught quickly without visual experience during critical periods. *Scientific reports*, *5*, 15359. doi:10.1038/srep15359

Rolfs, M., & Carrasco, M. (2012). Rapid simultaneous enhancement of visual sensitivity and perceived contrast during saccade preparation. *Journal of Neuroscience, 32*(40), 13744-13752a. doi: 10.1523/JNEUROSCI.2676-12.2012

Simons, D. J., & Chabris, C. F. (1999). Gorillas in Our Midst: Sustained inattentional blindness for dynamic events. *Perception, 28*(9), 1059-1074. doi:10.1068/p281059

Stewart, E. (2016). *A journey through time and space: The spatiotemporal profile of attention relative to saccade and reach. Research Theses.* doi: 10.4225/55/5924e05811641

Stewart, E. E. M., & Ma-Wyatt, A. (2015). The spatiotemporal characteristics of the attentional shift relative to a reach. *Journal of vision, 15*(5), 10. doi:10.1167/15.5.10

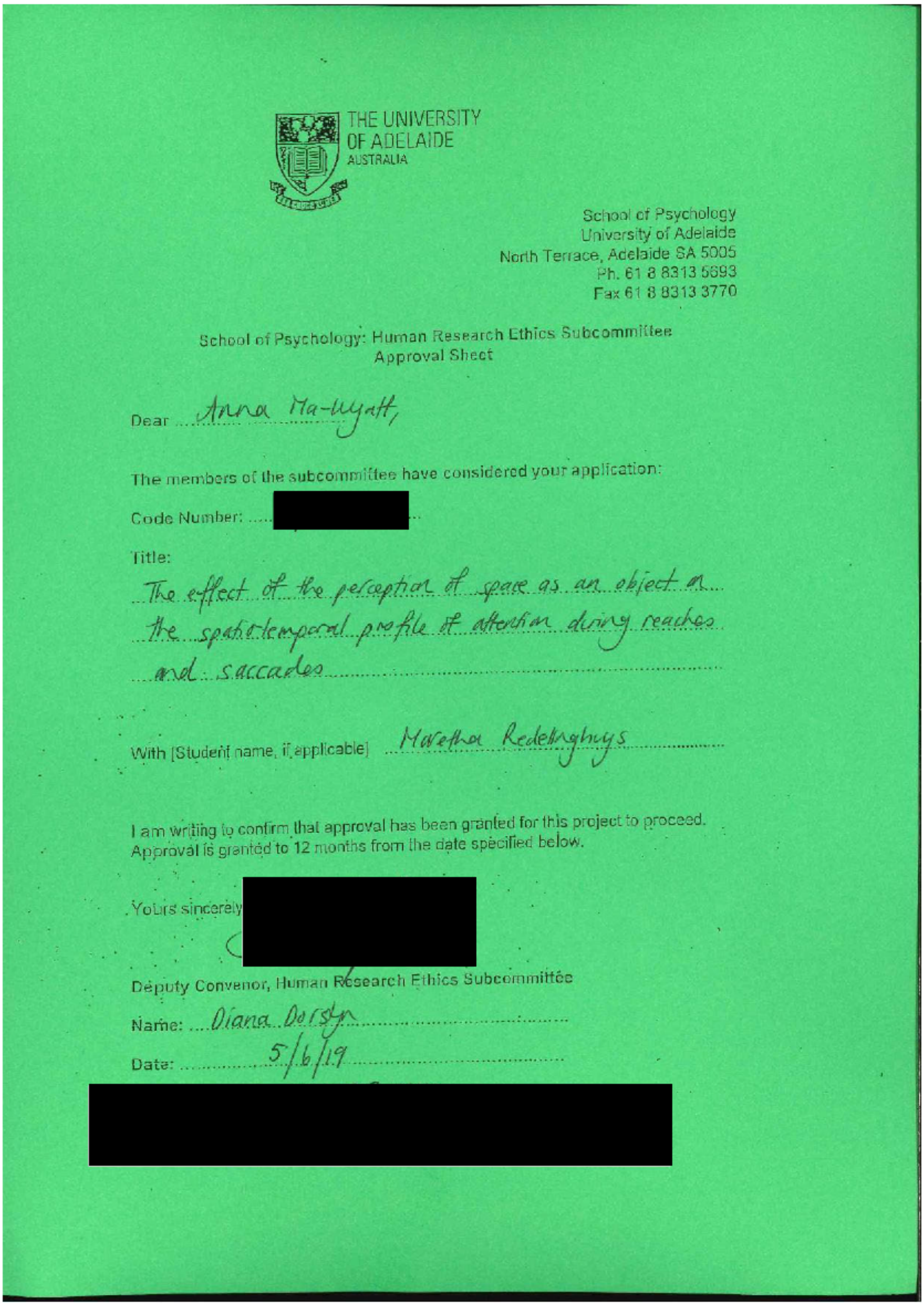
Stewart, E. E. M., & Ma-Wyatt, A. (2017). The profile of attention differs between locations orthogonal to and in line with reach direction. *Attention, Perception, & Psychophysics*, *79*(8), 2412-2423. doi: 10.3758/s13414-017-1400-z

Verghese, P., & Stone, L. S. (1996). Perceived visual speed constrained by image segmentation. *Nature, 381*(6578), 161. doi: 10.1038/381161a0

Verghese, P., & Stone, L. S. (1997). Spatial Layout Affects Speed Discrimination. *Vision Research, 37*(4), 397-406. doi:10.1016/S0042-6989(96)00155-1

Watson, A. B., & Pelli, D. G. (1983). QUEST: A Bayesian adaptive psychometric method. *Perception & Psychophysics, 33*(2), 113-120. doi: 10.3758/BF03202828

Appendix A – Ethics Approval



THE UNIVERSITY
OF ADELAIDE
AUSTRALIA

School of Psychology
University of Adelaide
North Terrace, Adelaide SA 5005
Ph. 61 8 8313 5693
Fax 61 8 8313 3770

School of Psychology: Human Research Ethics Subcommittee
Approval Sheet

Dear Anna Ma-Wyatt,

The members of the subcommittee have considered your application:

Code Number: [redacted]

Title:
The effect of the perception of space as an object on the spatiotemporal profile of attention during reaches and saccades

With [Student name, if applicable] Maretha Redelinghuys

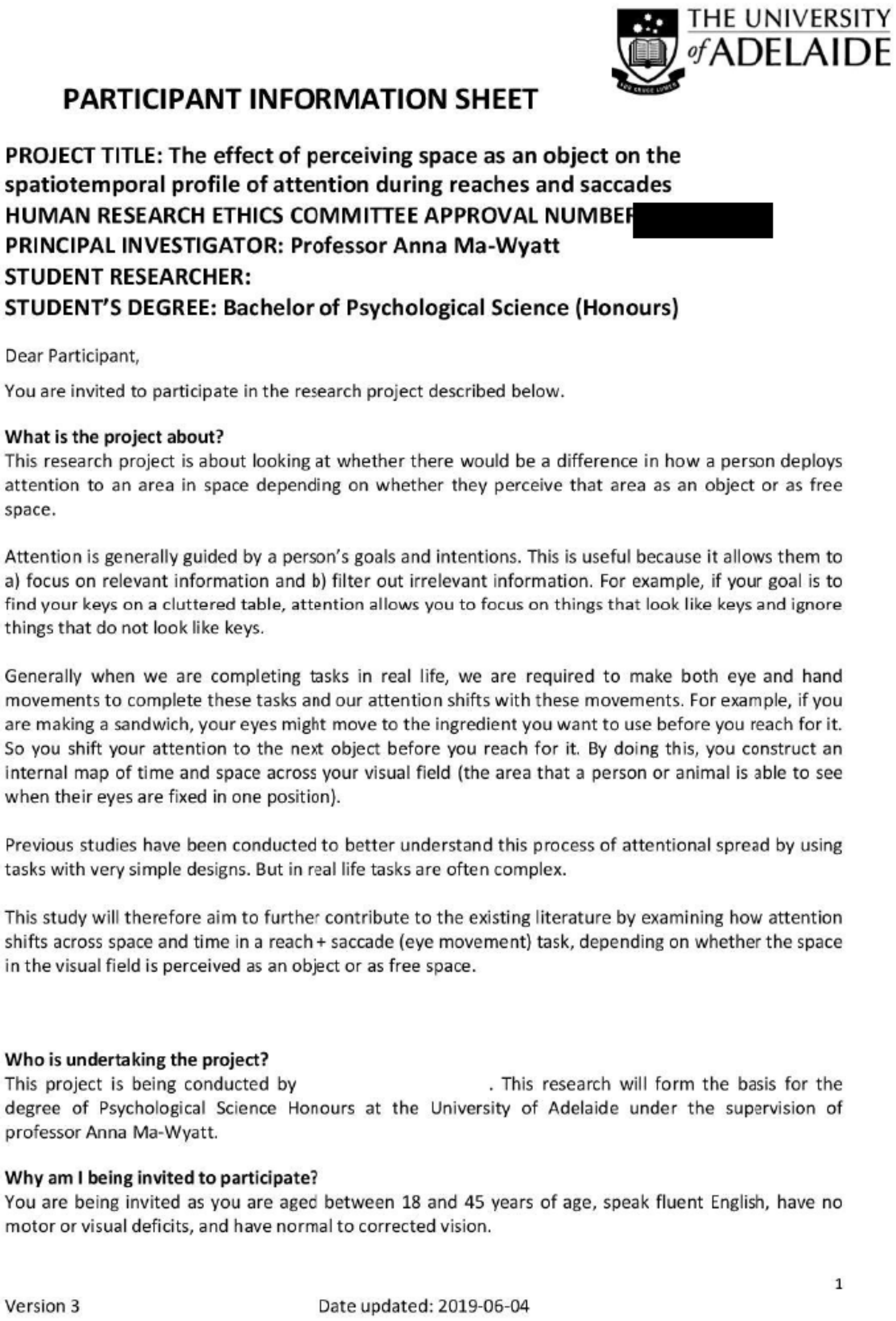
I am writing to confirm that approval has been granted for this project to proceed. Approval is granted to 12 months from the date specified below.

Yours sincerely [redacted]

Deputy Convenor, Human Research Ethics Subcommittee
Name: Diana Dorstyn
Date: 5/6/19

[redacted]

Appendix B – Experiment Information Sheet



THE UNIVERSITY *of* ADELAIDE

PARTICIPANT INFORMATION SHEET

PROJECT TITLE: The effect of perceiving space as an object on the spatiotemporal profile of attention during reaches and saccades
HUMAN RESEARCH ETHICS COMMITTEE APPROVAL NUMBER [redacted]
PRINCIPAL INVESTIGATOR: Professor Anna Ma-Wyatt
STUDENT RESEARCHER:
STUDENT'S DEGREE: Bachelor of Psychological Science (Honours)

Dear Participant,

You are invited to participate in the research project described below.

What is the project about?
This research project is about looking at whether there would be a difference in how a person deploys attention to an area in space depending on whether they perceive that area as an object or as free space.

Attention is generally guided by a person's goals and intentions. This is useful because it allows them to a) focus on relevant information and b) filter out irrelevant information. For example, if your goal is to find your keys on a cluttered table, attention allows you to focus on things that look like keys and ignore things that do not look like keys.

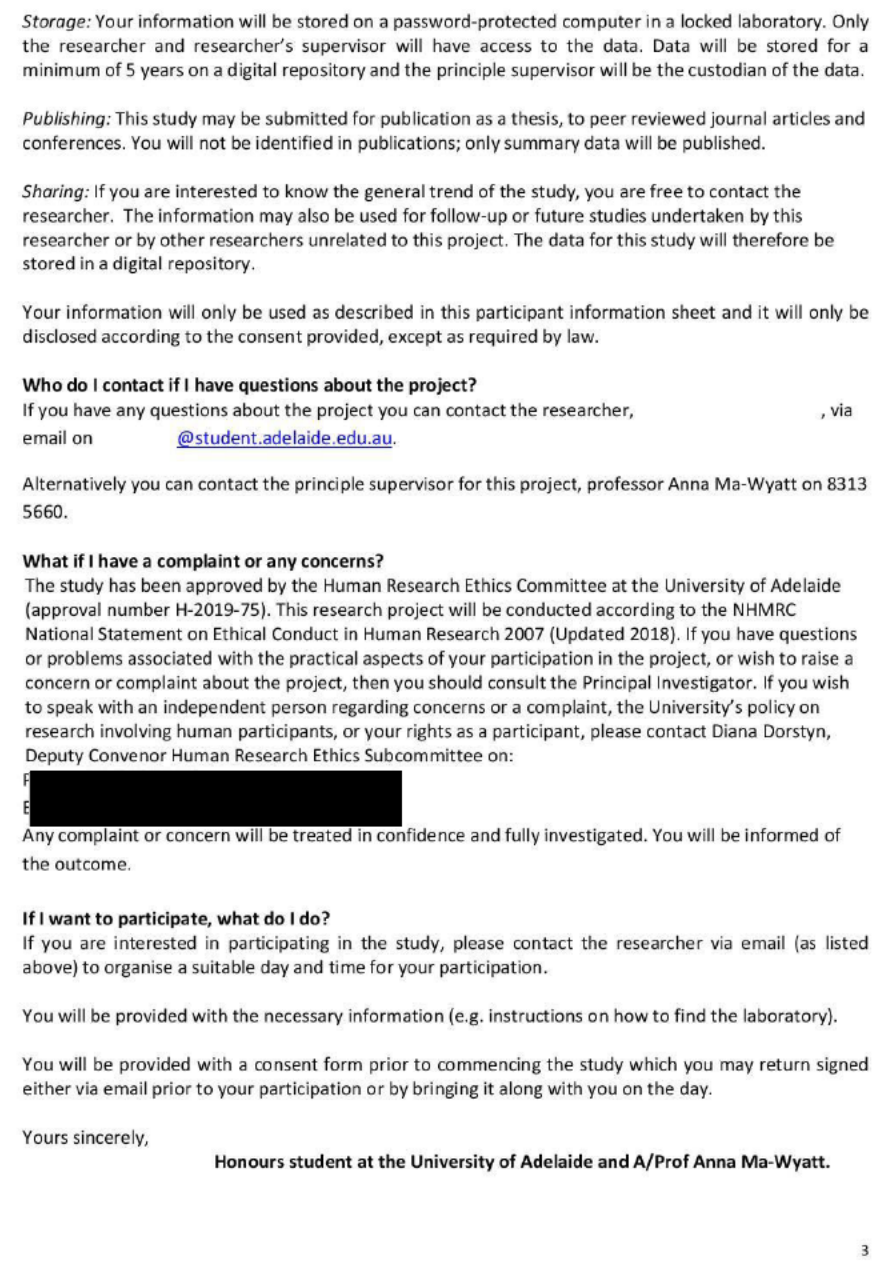
Generally when we are completing tasks in real life, we are required to make both eye and hand movements to complete these tasks and our attention shifts with these movements. For example, if you are making a sandwich, your eyes might move to the ingredient you want to use before you reach for it. So you shift your attention to the next object before you reach for it. By doing this, you construct an internal map of time and space across your visual field (the area that a person or animal is able to see when their eyes are fixed in one position).

Previous studies have been conducted to better understand this process of attentional spread by using tasks with very simple designs. But in real life tasks are often complex.

This study will therefore aim to further contribute to the existing literature by examining how attention shifts across space and time in a reach + saccade (eye movement) task, depending on whether the space in the visual field is perceived as an object or as free space.

Who is undertaking the project?
This project is being conducted by . This research will form the basis for the degree of Psychological Science Honours at the University of Adelaide under the supervision of professor Anna Ma-Wyatt.

Why am I being invited to participate?
You are being invited as you are aged between 18 and 45 years of age, speak fluent English, have no motor or visual deficits, and have normal to corrected vision.



Storage: Your information will be stored on a password-protected computer in a locked laboratory. Only the researcher and researcher's supervisor will have access to the data. Data will be stored for a minimum of 5 years on a digital repository and the principle supervisor will be the custodian of the data.

Publishing: This study may be submitted for publication as a thesis, to peer reviewed journal articles and conferences. You will not be identified in publications; only summary data will be published.

Sharing: If you are interested to know the general trend of the study, you are free to contact the researcher. The information may also be used for follow-up or future studies undertaken by this researcher or by other researchers unrelated to this project. The data for this study will therefore be stored in a digital repository.

Your information will only be used as described in this participant information sheet and it will only be disclosed according to the consent provided, except as required by law.

Who do I contact if I have questions about the project?

If you have any questions about the project you can contact the researcher, , via email on @student.adelaide.edu.au.

Alternatively you can contact the principle supervisor for this project, professor Anna Ma-Wyatt on 8313 5660.

What if I have a complaint or any concerns?

The study has been approved by the Human Research Ethics Committee at the University of Adelaide (approval number H-2019-75). This research project will be conducted according to the NHMRC National Statement on Ethical Conduct in Human Research 2007 (Updated 2018). If you have questions or problems associated with the practical aspects of your participation in the project, or wish to raise a concern or complaint about the project, then you should consult the Principal Investigator. If you wish to speak with an independent person regarding concerns or a complaint, the University's policy on research involving human participants, or your rights as a participant, please contact Diana Dorstyn, Deputy Convenor Human Research Ethics Subcommittee on:

[redacted]

Any complaint or concern will be treated in confidence and fully investigated. You will be informed of the outcome.

If I want to participate, what do I do?

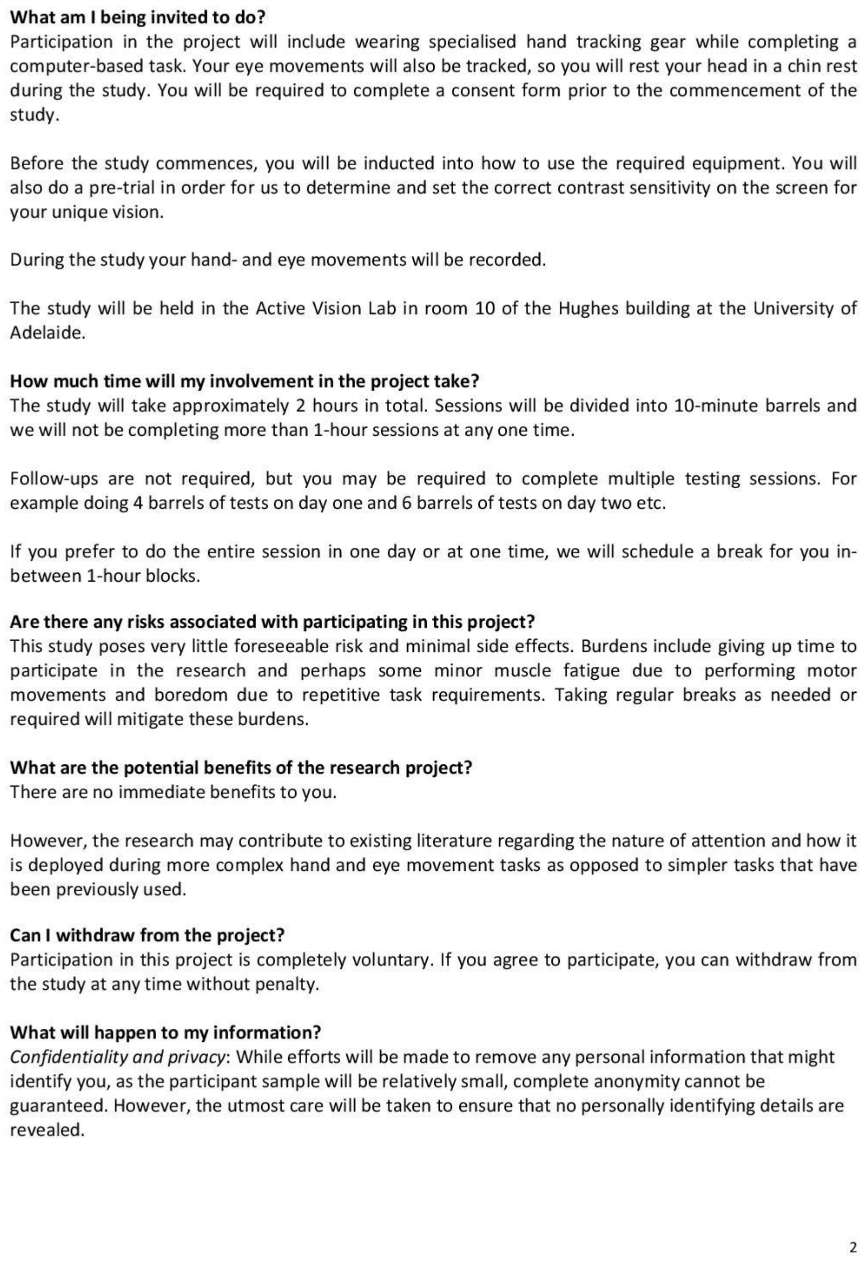
If you are interested in participating in the study, please contact the researcher via email (as listed above) to organise a suitable day and time for your participation.

You will be provided with the necessary information (e.g. instructions on how to find the laboratory).

You will be provided with a consent form prior to commencing the study which you may return signed either via email prior to your participation or by bringing it along with you on the day.

Yours sincerely,

Honours student at the University of Adelaide and A/Prof Anna Ma-Wyatt.



What am I being invited to do?
Participation in the project will include wearing specialised hand tracking gear while completing a computer-based task. Your eye movements will also be tracked, so you will rest your head in a chin rest during the study. You will be required to complete a consent form prior to the commencement of the study.

Before the study commences, you will be inducted into how to use the required equipment. You will also do a pre-trial in order for us to determine and set the correct contrast sensitivity on the screen for your unique vision.

During the study your hand- and eye movements will be recorded.

The study will be held in the Active Vision Lab in room 10 of the Hughes building at the University of Adelaide.

How much time will my involvement in the project take?
The study will take approximately 2 hours in total. Sessions will be divided into 10-minute barrels and we will not be completing more than 1-hour sessions at any one time.

Follow-ups are not required, but you may be required to complete multiple testing sessions. For example doing 4 barrels of tests on day one and 6 barrels of tests on day two etc.

If you prefer to do the entire session in one day or at one time, we will schedule a break for you in-between 1-hour blocks.

Are there any risks associated with participating in this project?
This study poses very little foreseeable risk and minimal side effects. Burdens include giving up time to participate in the research and perhaps some minor muscle fatigue due to performing motor movements and boredom due to repetitive task requirements. Taking regular breaks as needed or required will mitigate these burdens.

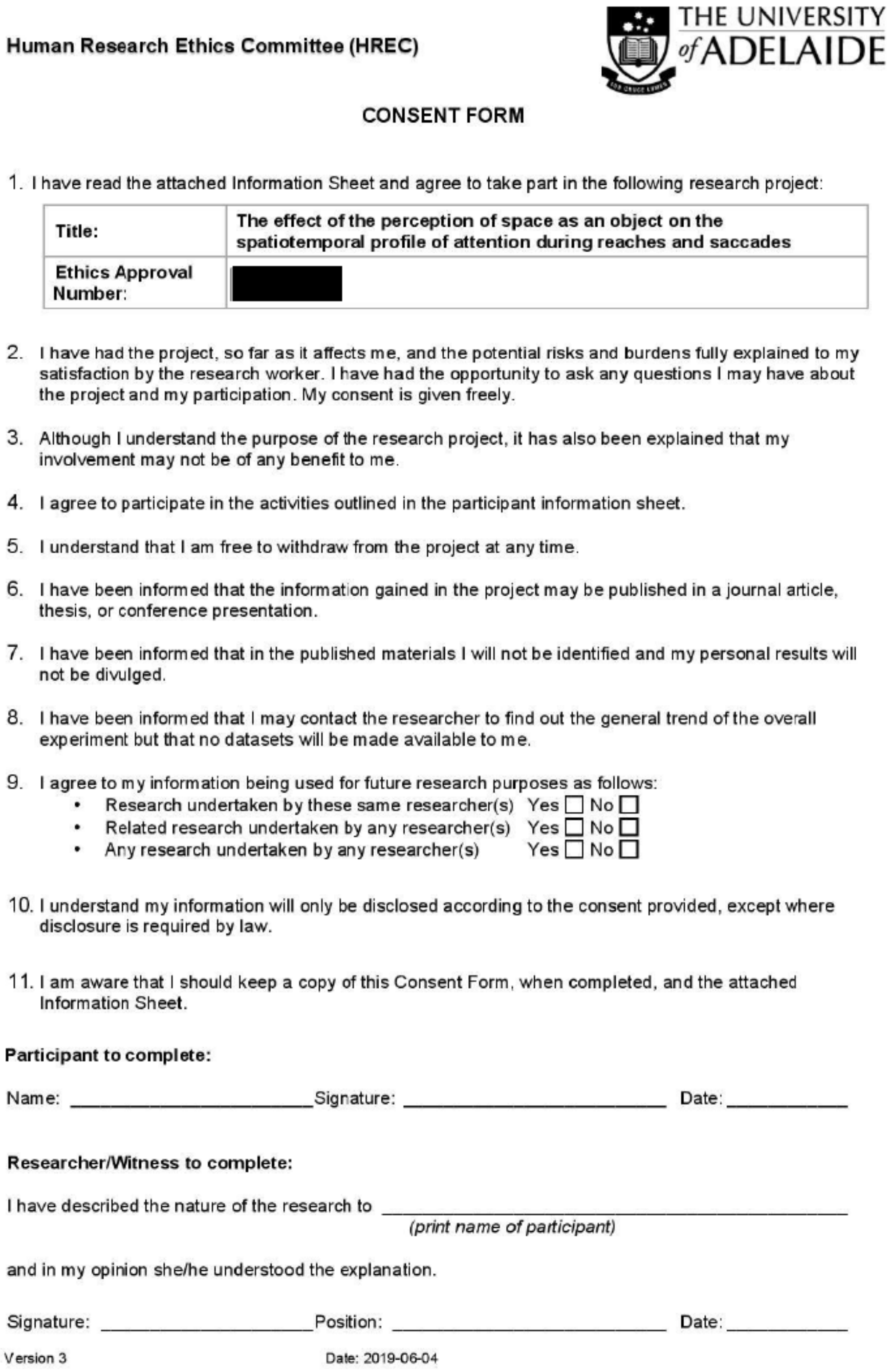
What are the potential benefits of the research project?
There are no immediate benefits to you.

However, the research may contribute to existing literature regarding the nature of attention and how it is deployed during more complex hand and eye movement tasks as opposed to simpler tasks that have been previously used.

Can I withdraw from the project?
Participation in this project is completely voluntary. If you agree to participate, you can withdraw from the study at any time without penalty.

What will happen to my information?
Confidentiality and privacy: While efforts will be made to remove any personal information that might identify you, as the participant sample will be relatively small, complete anonymity cannot be guaranteed. However, the utmost care will be taken to ensure that no personally identifying details are revealed.

Appendix C – Consent Form



Human Research Ethics Committee (HREC)

THE UNIVERSITY of ADELAIDE

CONSENT FORM

1. I have read the attached Information Sheet and agree to take part in the following research project:

Title:	**The effect of the perception of space as an object on the spatiotemporal profile of attention during reaches and saccades**
Ethics Approval Number:	[redacted]

2. I have had the project, so far as it affects me, and the potential risks and burdens fully explained to my satisfaction by the research worker. I have had the opportunity to ask any questions I may have about the project and my participation. My consent is given freely.

3. Although I understand the purpose of the research project, it has also been explained that my involvement may not be of any benefit to me.

4. I agree to participate in the activities outlined in the participant information sheet.

5. I understand that I am free to withdraw from the project at any time.

6. I have been informed that the information gained in the project may be published in a journal article, thesis, or conference presentation.

7. I have been informed that in the published materials I will not be identified and my personal results will not be divulged.

8. I have been informed that I may contact the researcher to find out the general trend of the overall experiment but that no datasets will be made available to me.

9. I agree to my information being used for future research purposes as follows:
   - Research undertaken by these same researcher(s) Yes ☐ No ☐
   - Related research undertaken by any researcher(s) Yes ☐ No ☐
   - Any research undertaken by any researcher(s) Yes ☐ No ☐

10. I understand my information will only be disclosed according to the consent provided, except where disclosure is required by law.

11. I am aware that I should keep a copy of this Consent Form, when completed, and the attached Information Sheet.

Participant to complete:

Name: ______________________ Signature: ________________________ Date: ___________

Researcher/Witness to complete:

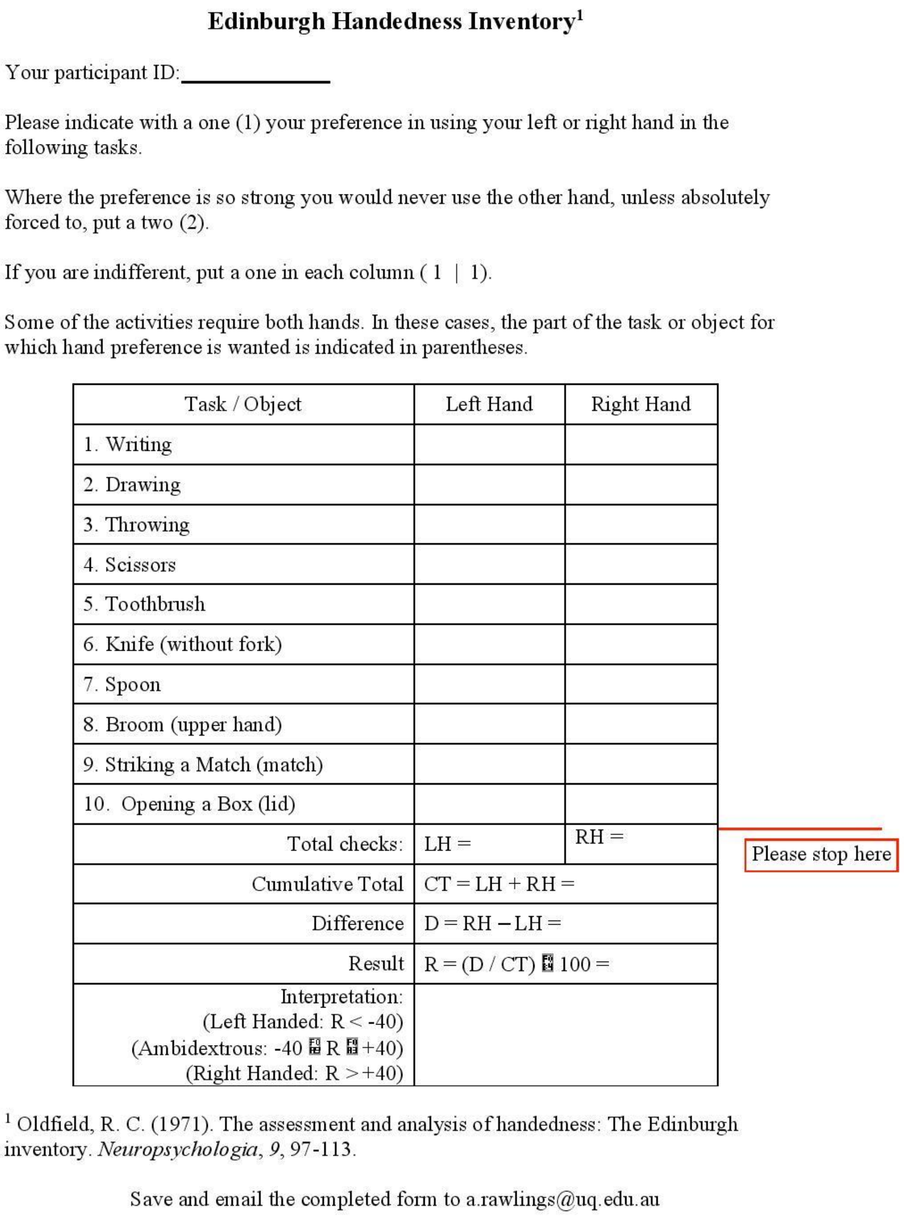
I have described the nature of the research to ____
(print name of participant)

and in my opinion she/he understood the explanation.

Signature: ___________________ Position: _________________________ Date: ___________

Version 3 Date: 2019-06-04

Appendix D – Edinburg Handedness Inventory



Edinburgh Handedness Inventory[1]

Your participant ID:______________

Please indicate with a one (1) your preference in using your left or right hand in the following tasks.

Where the preference is so strong you would never use the other hand, unless absolutely forced to, put a two (2).

If you are indifferent, put a one in each column (1 | 1).

Some of the activities require both hands. In these cases, the part of the task or object for which hand preference is wanted is indicated in parentheses.

Task / Object	Left Hand	Right Hand
1. Writing		
2. Drawing		
3. Throwing		
4. Scissors		
5. Toothbrush		
6. Knife (without fork)		
7. Spoon		
8. Broom (upper hand)		
9. Striking a Match (match)		
10. Opening a Box (lid)		
Total checks:	LH =	RH =
Cumulative Total	CT = LH + RH =	
Difference	D = RH – LH =	
Result	R = (D / CT) × 100 =	
Interpretation: (Left Handed: R < -40) (Ambidextrous: -40 ≤ R ≤ +40) (Right Handed: R > +40)		

Please stop here

[1] Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*, 97-113.

Save and email the completed form to a.rawlings@uq.edu.au

Appendix E – Participant Information Sheet

Participant number: ________

Participant information Sheet

1. **First Name**:
2. **Last Name**:
3. **Email**:
4. **Gender**: Male ☐ Female ☐ Other ☐ Prefer not to specify ☐
5. **Ethnicity**:
6. **Native/Home Language(s)**:
7. **Age**:
8. **Highest level of education**:
9. **Do you have any motor deficits**: Yes☐ No ☐
10. **Do you have normal or corrected vision**: Normal☐ Corrected ☐
11. **If corrected, do you know your correction number**:

    Left Eye Right Eye

12. **If you do not know your correction number, are you**:

    Farsighted ☐ Near-sighted ☐

Appendix F – Participant Instruction Sheet

Hi! Thank you for participating!

A bit about this study:
We are interested in looking at how people deploy attention across time and space and whether perceiving space differently affects this process.

This study has received ethics approval from the Ethics Committee at the University of Adelaide.

You can stop me to ask questions at any time.

Some paperwork:

1. Information Sheet. Please read this, it will give you some more information. There are numbers on there you can call if you have any complaints and you can email myself or my supervisor if you would like to learn more about the outcomes of the study. If you have any questions after reading it, let me know.
2. Consent form. Please read this and sign two copies. One for you to take and one for me to keep. You are free to withdraw from the study at any time without any penalty.
3. Edinburgh Handedness Inventory. This is a short test to measure whether your handedness. Please complete the form up until where it asks you to stop.
4. Participant Details Sheet. This is to collect some

Some Questions for you:

1. Do you have any motor deficits?
2. Do you have any visual deficits?
3. Do you wear glasses for anything at 40cm away?
   If yes, please wear them during the experiment

What will we be going through:

- First I will talk about and show you the equipment we will be using
- I will then talk about the tests we will do today including: What they look like, how they work, how long they will take etc.

Any questions so far?

Equipment:

- In this set-up, you will be using the Eyelink eye-tracker and a touch screen monitor.
- You will lean your chin on he chinstrap, and make sure you can see the screen properly.
- On the other screen, we will record your hand and eye movements. I will be sitting behind the curtain so as not to disturb you, but you may call out to me if you need anything.

IMPORTANT:

- When you have your head in the headrest, remember to press/keep your head against the rest at all times. This is so that we can keep the distance of your eyes to the screen as well as the angle consistent.
- You will need to use the number pads during the test. It might be helpful to position your fingers on the correct numbers before you put your head in the rest.
- Once you have started a test, please do not take your head out of the headrest until the test is done! If you do, we will need to start over.

Procedure:

There will be three 'types' of tests altogether.

- First we will do a baseline test for us to determine your contrast sensitivity or contrast threshold. This is the level at which you can/cannot detect a difference between the background and foreground.
- Then we will do condition 1 of the test.
- And then we will do condition 2 of the test.
- Before each 'test', you will have the opportunity to have a look at the layout of the screen and we will do a short practice run so that you can become familiar with the procedure and equipment.
- It should last for about two hours and we will take a break after at least an hour, but you can have a break anytime you feel you need one.

Any questions so far?

Let's look at the baseline/test 1

About this test:

- For this test there will be 3 different layouts.
- You will do three blocks for each layout.
- Each block should take about 3 minutes.
- So altogether this test should last for about 30 minutes.
- You can have a break at any time, just kindly wait until the block you have started is finished first.

Baseline Layout:

- The dark dot at the bottom of the screen is the fixation point. This is where you will look and focus before the test starts.
- Please keep your eyes on this point at all times during the test.
- The grey circles are where the probe (a dot) will appear. It can appear at any one of the probe locations at any time during the test.
- Sometimes you will not be able to see the probe – that's ok because it will be below the threshold you are able to see. Just take your best guess where you think it was. Studies have shown that people are pretty good with 'guessing' even if they think they didn't see it. **Important**: Don't overthink it!
- There are three different 'layouts' for this test and you will do three blocks for each layout.
- You can have a practice run for each layout to familiarise yourself with the sequence and procedure.

Steps for test:

- Rest your head in the chinrest and look at the screen. **Remember to keep your head firmly against the headrest.**
- On the home screen, fixate and keep looking at the black fixation point at the bottom of the screen. **Remember to keep looking at this point during the entire test.**
    1. When you first start, there will be a grey screen followed by a short beep to say 'Ready when you are!' That is how you will know that the test has started.
    2. To start, press the spacebar. You may press the spacebar with your left hand while you keep your fingers on the correct keys on the number pad.

3. After you press spacebar, the home screen will come on – stare at the fixation point.
4. On your first trial, when the home screen comes on, the probe will be presented immediately in one of the probe locations. At the same time as the probe is presented, you will hear another short beep to tell you that the probe has been presented (you need the beep because you wont be able to see the probe all the time).
5. You then have to decide where you think you saw the probe.
6. If you think you saw it on the left side, press 1 on the number pad
7. If you think you saw it on the right side, press 3 on the number pad
8. After you have pressed 1 or 3, there will be a long beeeeep to signal the end of the trial.
9. The long beep will be followed by a short beep to say "New trial, ready when you are!"
10. And then we are back at step 1! We will keep going until the block ends.

Any questions so far?

Let's practice!

Let's look at the condition 1/2 test 2/3

About this test:

- For this test there will be only 1 layout – the home screen.
- You will do 8 blocks.
- Each block should take about 3 minutes.
- So altogether this test should last for about 30 minutes.
- For this test, we will need to do a calibration before each block. This is because we need to be sure that the eyelink is correctly tracking your eye movements so that the data can be correctly recorded.
- You will also need to make reaching movements during this test.
- Please keep your dominant hand on the mouse and reach with the same hand when required.
- You will need to use the same hand you made a reach with to press the numbers on the number pad – so it may be a bit tricky!
- **Remember, once you have been calibrated, please do not take your head out of the headrest or we will need to re-start the block.** You will need to stay like this for at least as long as it takes to complete a block so make sure you are comfortable!

- You can have a break at any time, just kindly wait until the block you have started is finished first.

Calibration:

- Rest your head in the chinrest and look at the screen. **Remember to keep your head firmly against the headrest.**
- When we do the calibration, the screen will be black.
- Please look and keep looking at the middle of the screen.
- When the calibration starts, a white dot will appear.
- Please follow the dot and stare at it once it does. Keep staring at it until it moves to a different location.
- The dot will move to different locations on the screen.
- Once it moves, please follow it with your eyes.
- Do not try to guess where the dot will be.
- **Remember to keep your head in the headrest when the calibration is done!** You will need to stay like this for at least as long as it takes to complete a block so make sure you are comfortable!

- We will then start the test.

Condition 1 Layout:

- On this layout, there will be 7 light grey circles. These are the probe locations.
- During the test, the probe will appear at any of the 7 locations.
- There are also 2 dark grey circles. These are the reaching targets – the spots on the screen where you need to reach to and touch during the test.
- The dark dot at the bottom of the screen is the fixation point. This is where you will look and focus before the test starts.
- Remember, sometimes you will not be able to see the probe – that's ok because it will be below the threshold you are able to see. Just take your best guess where you think it was. Studies have shown that people are pretty good with 'guessing' even if they think they didn't see it. **Important**: Don't overthink it!
- You can have a practice run before starting the test to familiarise yourself with the sequence and procedure.

Steps for test:

1. Place and keep your hand on the mouse.

2. On the home screen, fixate and keep looking at the black fixation point at the bottom of the screen. **You will not be looking at this dot for the entire test.**
3. Click and hold the mouse until you are ready to start.
4. Once you are ready, let go of the mouse.
5. After a variable amount of time, a beep will sound and the fixation point will vanish from the screen.
6. Once you heard the beep and the fixation point disappears, it means you need to make an eye movement and reach to the correct target location on the screen.
7. If you hear a high tone, look at and reach to and touch the left target as fast as you can. Keep looking at the target until the next screen comes on.
8. If you hear a low tone, look at and reach to and touch the right target as fast as you can. Keep looking at the target until the next screen comes on.
9. During this time, the probe will appear at one of the 7 target locations.
10. After you have touched the screen, a second screen will appear showing where the probe could have been in the target locations with the text "Where was the probe? Press the corresponding key on the number pad".
11. On the keyboard, pick the corresponding number of where you think the probe appeared (1, 2, 3, 4, 5, 6, 7). If you don't know or aren't sure, make your best guess.
12. The screen will then return to the home screen, and the test will start again.

Any questions so far?

Let's practice!