Attentional Facilitation During Reaches and Saccades in a Cluttered Setting

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This thesis is submitted in partial fulfilment of the Honours degree of Bachelor of Psychological Science (Honours)

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November 2018

Word Count: 7826

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Abstract

When people make a movement to reach or saccade to an object, there is evidence that attention shifts to the goal of the movement. While eye-hand movements are a crucial part of daily living, research into how attention is deployed during eye-hand movements has focused on sparse arrays. This experiment takes the next step towards documenting the spatiotemporal profile of attentional facilitation during eye and hand movements in the real world by using a design with a complex visual array of multiple targets and distractors to better mimic natural surroundings. Participants made a reach or saccade and reach to one of two targets, presented within an array of seven constantly present distractors, and a probe (contrast increment) was shown at one of these locations on each trial. The stimulus onset asynchrony (SOA) between cue and probe varied from trial to trial. Correct identification of the probe location was used to quantify attention. In line with previous findings, higher probe detection performance was found for the saccade + reach condition compared to the reach alone condition, supporting theories that suggest perceptual benefits with the localisation of overt attention to a target. Reach latencies were generally longer than previously observed in other studies and there was also a higher rate of data exclusion. Altogether, these results suggest the possibility of a different pattern of attentional facilitation across complex versus simple scenes. These findings reaffirm the need for more naturalistically-representative design layouts to be employed in future studies on attentional facilitation.

Declaration

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5th November 2018

Acknowledgements

First and foremost, I would like to thank my supervisor, Assistant Professor Anna Ma-Wyatt, for your time, knowledge, and guidance throughout the entire project. Your endless patience, kindness, reassurance, and supply of chocolates gave me courage and confidence to do my best and push through the year. I am grateful for your late-night emails, your cupcake of encouragement before my presentation, and that I was fortunate enough to have you as my supervisor.

I would also like to thank my fellow lab mates, Jess and Adam, for your friendship and help throughout the various stages of this project. The sun might not shine into Hughes 110 but I feel its warmth and joy everyday with your presence and conversations.

A big thanks to my fellow members of the 2018 Honours cohort for making this year so enjoyable and for being such a supportive group.

Finally, thank you Ying for being the best little sister. Your hugs and games of catch saved me from the fate of turning into stone by my laptop.

Attentional Facilitation During Reaches and Saccades in a Cluttered Setting

Background

Vision is a valuable sense that allows normally-sighted individuals to take in their surroundings, make sense of it, and navigate within it to complete daily tasks. Understanding how visual processes operate to provide these abilities opens a window into human cognition, as it is well established that goals and intentions provide top-down guidance to the deployment of conscious eye movements in the form of selective attention (Carrasco, 2011; Kowler, 2011; Land, 2009), which focuses on relevant targets while filtering out irrelevant ones. An overarching question in vision and cognitive neuroscience research is indeed whether it is possible to predict an individual's thought processes purely from their eye movements. In natural behaviour, it is also observed that eye movements are closely coupled with reaching and grasping hand movements during task completion, making it valuable to research the two together and independently to make comparisons so that models can be created to explain how attentional resources are shared between eye and hand movements in natural behaviour. Research into this topic has revealed both similarities and differences in the profile of attentional facilitation, building up a picture of how attention is organised for these two movements when performing simple movements within a simple visual scene (e.g. Stewart & Ma-Wyatt, 2015; 2017). However, in a natural environment it is not uncommon to find a target in a cluttered environment. There are open questions about how work conducted with simple stimuli will translate to more complex scenes. Since the goal of experimental and theoretical work is to enable prediction of external behaviours in the real world, the present experiment takes a next step in research and studies the profile of attentional facilitation for hand and eye movements using a visual array of multiple targets and probes as a basic simulation of the often complex real-world environment.

Eye Movements and Hand Movements

The eyes in movement. To understand how eyes and hands are used together, and to study how they interact through time and space to complete simple everyday tasks, Land, Mennie, and Rusted (1999) and later Hayhoe, Shrivastava, Mruczek, and Pelz (2003) used video cameras to track the eye and hand movements of participants who were instructed to make a cup of tea and make a sandwich, respectively. By sectioning participants' movements into components of the overall goal and aligning the sequences of their eye and hand movements for each component, the researchers observed that the pattern of eye fixations on objects were closely aligned with manipulation of them by the hands. This finding was taken as further support for the close connection between eye and hand movements, which will be discussed further in the following section.

A behavioural unit. Hand and eye movements are a common behavioural unit in nature. Although individuals may assume that their movements in performing a familiar task are carried out automatically, what their hands are doing are in fact still checked by visual fixations (Land et al., 1999). In experiments involving a single eye movement (saccade) and hand movement to a lone target, the temporal difference between when the saccade and the hand movement lands on the target was close to zero (Abrams, Meyer, & Kornblum 1990), and eye-hand latencies ranged from 60-100ms. For a more naturalistic task like making a cup of tea, eye-hand latencies might vary but there is a strong spatial correlation still between the endpoints of eye and hand (e.g. Land et al., 1999). Neurologically, an explanation for this close association is provided by the involvement of the parietal lobe in both reaching and grasping and saccadic eye movements, especially in managing hand-eye coordination (Land et al., 1999; Land, 2009). Returning to behavioural experiments, a study by Bekkering, Adam, Kingma, Huson, and Whiting (1994) provides insight into the specificity of the hand-eye movement link by comparing saccadic reaction time (RT) to a target when performed alone, with a concurrent reach to the same target, or with a finger button press and no hand movement. When comparing the latter two conditions with the RT of a lone saccade, a significantly slower RT was found for saccades made with a reach, while there was no significant difference for saccades made with a button press. This comparison can be used to suggest a further element of functional specificity in the overlap between the hand and eye motor systems — that is to say, non-independence in the operations of the two systems seems to be specific to whether or not the hand and eye movements have the same function, such as locating towards the same target.

Mechanisms of goal-directed saccade and reaches. Goal-directed hand and eye movements can occur at a high level of synchrony, probably because the same visual information is used to program both the movement and the saccade. Before a saccade is made, a target is localised in the periphery, which sends visual information that is then used to program and initiate the reach and saccade (e.g. Abrams et al, 1990; Gegenfurtner & Franz, 2007; Ma-Wyatt & McKee, 2006). Abrams et al. (1990) showed that for a single, isolated target the saccadic or reaching movement is programmed only after the target has been selected by the periphery, allowing them to be deployed simultaneously.

In a natural environment, there may be several targets that are potentially relevant for actions. The challenge then is to understand how these are represented and prioritised over time, and how a person decides to make a reach or saccade to a given location. Itti and Koch (2001) have a computational model of how a salience map might be used to direct saccades during both simple and complex scenes. They suggested that such a schema is supported both by encoding of stimulus attributes as well as higher level representations of “salience”. At this higher level of cognitive function, Land (2009) suggested a schema system as the controller that assigns the locations for selection by the periphery based on the checklist of single action activities that are held within the system, which link into an action sequence that ends in the achievement of the overall objective. The cortical area that is the most associated with the schema system is the dorsolateral prefrontal cortex (DLPFC), which is known to be involved in purposeful action and is identified to be responsible for organising individual actions into action sequences (Land, 2009).

Goal-directed Movements and Attention

Selective attention. Underlying both the cognitive and behavioural elements of goal-directed movement is selective attention, which focuses individuals to relevant stimuli in the environment while filtering out irrelevant information in the background. The reason why attention is selective can be explained by Kahneman’s (1873) limited-capacity model of attention, which states that humans have a fixed amount of cognitive resources that are shared between all foci of attention. In vision, goal-directed attention is categorised as spatial attention, which denotes the selection of specific areas within the visual field on the basis of its location and immediate relevance to the individual’s purposes. There are also other forms of visual attention, such as feature-based attention, that are governed by the salience of objects within the visual field; that is to say, they are attracted to objects with characteristics that make them stand out from the background, such as different colours and orientations (Carrasco, 2011). Since the design of the present experiment involves uniform targets and distractors, these forms of attention will not be discussed in further detail.

Attentional resources. The allocation of attentional resources is sensitive to the demands of the task (Baldauf, Cui, & Anderson, 2008). Tasks that require a higher resolution focus, such as those that require an accurate identification of the object at the target location, are marked by the localisation of a greater amount of attentional resources to the target and less to other areas in the visual field (Baldauf & Deubel, 2009). At the other end of the line, activities such as scanning the environment for potential targets, which do not require a clear focus on any objects. allow attentional resources to be spread across a greater span of the visual field (Kowler, 2011). The sensitivity of attentional resource allocation to task demands are illustrated neurologically in Muller. Bartelt, Donner. Villringer, and Brandt's (2003) study, who note that as the area of attentional spread increases, the extent of activation of the retinotopic visual cortex also increases, but the level of neuronal activity across the area of activation is lower compared to when attention is concentrated to a smaller region. This trade-off between sharp resolution and spread is a robust effect that has been observed over a range of experimental design layouts (Carrasco, 2011).

Saccades and attention. As has been discussed thus far, spatial attention is an important driver of saccadic eye movements to relevant locations in the visual field. Carrasco (2011) divides spatial attention into two types: overt attention, which is deployed peripherally without eye movements during the preparation stages of a saccadic or reaching movement, and overt attention, which is the shift of attention from one location to the other, accompanying an equivalent saccadic eye movement. Respectively, they are involved in the preparation and execution stages of saccadic eye movements, with the functions of determining target locations and guiding shifts in fixation to them.

It is well established that covert attention can simultaneously cover an extended area of the visual field (e.g. Carrasco, 2011; Kowler, 2011), attributable to its low-resolution and therefore the low attentional resource requirements in each area of its allocation (Muller et al., 2003). This also means that only a limited amount of information can be perceived about a target that is attended to covertly; extraction of the semantic meaning of an object after overt attention is directed to its location with the saccade (Kowler, 2011). In turn, overt attention has a limited spatial spread: since saccades involve the displacement and direction of foveal fixation, multiple saccades must be completed in sequential order (Carrasco, 2011; Zirnsak, Steinmetz, Noudoost, Xu, & Moore, 2014).

Independent mechanisms? The final element of the relationship between spatial attention and saccades to be discussed is the extent of association between saccades and attention, especially high-resolution perceptual attention. Can an object be fully attended to when a saccade is simultaneously made to a different location? Kowler, Anderson, Dosher, and Blaser (1995) devised a series of experiments involving a letter-recognition task that contained a central fixation cross and eight surrounding targets, the locations at which there were different alphabetical letters. On a given trial, one of the targets surrounding the central fixation point was be cued, to which participants are asked to make a saccade and report its letter; at the time of reporting, they were also be asked to report on a second stimulus that was present at a non-cued location. Comparing performance at the saccade goal and non-goal provided insight into whether perceptual attention, in distinction from low-resolution covert attention, can be deployed independently of saccades. When participants were informed that they must report two locations, but the location of the non-goal was unspecified, successful letter identification was observed only at the saccade goal, signalling that the level of resolution needed for interpretation of target information cannot be equally deployed across the wider visual layout to the other targets during the execution of a saccade (Kowler et al., 1995). The researchers then repeated the experiment with a prior cue of the non-goal before saccade start. In this condition, participants were able to accurately report the letter at the non-goal at the expense of a longer saccade latency to the goal (Kowler et al., 1995). These two results provide support for the non-independence of mechanisms underlying saccades and attentional shifts. Therefore, saccades require a shift in attention, and perceptual attention cannot be present at a non-target location without changes to the speed of saccade deployment.

Establishing this close association allows vision researchers to make the assumption of taking the saccadic process as a proxy for the selective attention process and allows benefits in the perception of a target from localised fixations to be attributed to selective attention.

Selective Attention in Research

Neural substrates of selective attention. The main cortical areas with involvement in spatially selective attention are the Frontal Eye Fields (FEF) and the Lateral Intraparietal Area (LIP; Moore, 2006). The importance of these areas in selection are illustrated by experimental studies conducted on monkeys described in Moore’s (2006) review — deactivation of these cortical regions caused deficits in monkeys’ ability to pick out visual targets from among distractors in a manner that is not attributable to visual or motor impairments. In particular, the FEF is linked to the physical mobilisation of saccades, as Hanes and Schall (1996) found that the RT of saccades are the same as the speed at which FEF neuronal activity reaches its maximum threshold, such that a faster rise in activity is associated with a shorter RT.

The relationship between these selective attention areas and the visual cortex, which receives and processes information from the retinas, or in other words enables sight, is one of reciprocal information transmission and feedback. Specifically, the DLPFC, i.e. the schema system, the FEF, and the LIP form an interconnected system responsible for the deployment of goal-directed intention and selective attention, the latter of which connects the system to the visual cortex (Land, 2009). All in all, these areas form a feedback loop between top-down instruction and visual information.

The direct link between the selective attention system and the cortical visual areas means that neural representations of the visual field are generated by prioritising information that is relevant to behavioural goals rather than accuracy of detail (Carrasco, 2011), once again emphasising on the value of mapping selective attention in understanding the processes of vision.

Attentional benefits: contrast sensitivity. One of the well-established benefits of selective attention is that it allows individuals to detect smaller differences in the luminance contrast between two stimuli, or in other words increase their contrast sensitivity. To verify paradigms for the involvement of selective attention in early visual processing, Bashinski and Bacharach (1980) directed participants' covert attention to one of two targets on either side of a central cue by indicating the likelihood that a contrast increment will occur at its location. They found that participants were consistently more sensitive at the location that was indicated. Carrasco, Penpeci-Talgar, and Eckstein (2000) explain this effect by stating that covert attention decreases the threshold for luminance contrast detection through signal enhancement at the target location. This signal enhancement theory of selective attention is in accordance with neurological evidence outlined by Moore (2006) for overt attention, namely that increments of contrast sensitivity is well predicted by the strength of activity in the Primary Visual Cortex (V1) as well as stimulation of the FEF, which combine to suggest that selective attention benefits contrast sensitivity by increasing the visual representation of the target stimulus. Given also that enhancements of visual characteristics can involve different attentional resource pools for different modalities (Morrone, Denti, & Spinelli, 2002); for instance, detection of colour differences will involve a different source of attention, it can be conversely suggested that enhancement in contrast sensitivity can be indicative of the presence of selective attention.

Based on this assertion, researchers developed the probe detection task, which generally involves presenting an array of stimuli on a screen and asking participants to detect changes in the luminance contrast of probes presented at threshold sensitivity while they saccade or reach towards a target. Since attending to a location boosts contrast sensitivity, participants' ability to accurately detect probes presented at various points in space and time relative to movement can be used to draw a map of selective attention across the visual field.

Spatiotemporal profile of selective attention. Meaningful contributions have been made to the construction of a spatiotemporal map of the facilitation of selective attention by researchers using probe-detection tasks within simple designs that involve single or few visual targets and probes. For example, Baldauf and Deubel (2009) studied the attentional facilitation of covert attention during the planning of a pointing sequence and found enhancements in contrast sensitivity at the targets of the sequence, consistent with previous observations concerning the pre-movement deployment of selective attention to relevant locations of the action goal (e.g. Hayhoe et al., 2003; Land et al., 1999). Different from conclusions about the spatial spread of covert attention, a perceptual benefit for contrast detection was not observed for probes presented between two reaching targets (Baldauf & Deubel, 2009; Kowler, 2011). With concurrent consideration of Heinze et al.'s (1994) finding that participants were able to attend to areas between targets when they do not need to prepare for a movement, the researchers explain that hand movement planning may require more precise selection of targets, which would need more attentional resources to be localised, leaving less available for stimuli in their surroundings.

Later, Stewart and Ma-Wyatt (2015) used a probe detection task containing probes at different directions to the target were presented at various times relative to cue onset to compare the spatial and temporal profiles of attentional facilitation during the saccade-only, reach-only, and saccade + reach movement processes. They found that peak facilitation of attention differs temporally between saccades and reaches, wherein attentional weighting generally favours reaching performance during the preparations and first stages of movement, after which there is an attentional trade-off between reaching and perceptual performance before attention comes to favour perceptual performance after the reaching movement reaches completion. Using these observations, the researchers suggest that although they involve a similar preparation process and pattern of cortical activation, there may actually still be different mechanisms involved in the attentional activation of saccades and reaches. Detailed investigations into the extent to which their profile of attentional facilitation differ will allow conjectures to be made about how attentional resources are shared between eye and hand movements during task completion. Several studies have also looked at the difference in attentional facilitation as a function of movement onset time, or as a function of the stimulus onset asynchrony (SOA) of the cue (e.g. Jonikatis & Deubel, 2011; Rolfs & Carrasco, 2012; Stewart & Ma-Wyatt, 2015; White, Rolfs, & Carrasco, 2013). The results of these studies suggest an increase in sensitivity (that is, attentional facilitation) in the lead up to the deployment of a movement.

The studies described in this section have used quite simple arrays to test the spread of attention with a hand or eye movement. While these results have been informative, it is not yet clear how they will translate to more naturalistic scenes.

Rationale

Since the end goal of experimental conclusions are to build predictive models of how a person will react in the external world, the present experiment takes a next step in research of the spatiotemporal profile of selective attention by aiming to provide insight into the facilitation of attention during hand and eye movements in a more complex visual scene, using an array of multiple targets and probes as a basic simulation of the complex real-world environment. Based on the findings of previous experiments (e.g. Baldauf & Deubel, 2009; Stewart & Ma-Wyatt, 2015), it is hypothesised that the spatiotemporal profile of attentional facilitation will differ on the basis of cue onset time and there will also be a significant difference between attentional modulation for conditions with a reach only, compared to saccade + reach conditions. It is also hypothesised that the spatiotemporal profile of attentional facilitation will change as a function of movement onset time and effector. Of note, since the profile of attentional facilitation for the saccade-only and saccade + reach movement conditions are similar (Stewart & Ma-Wyatt, 2015; 2017), the present experiment has elected to only test and compare a saccade + reach condition and a reach-only condition, which will still allow the spatiotemporal profile of reaching to be independently documented for comparison.

Method

Participants

Five participants completed the study. One was an author, and four were naive to the purposes of the experiment. Two participants were experienced psychophysical observers. All participants had normal or corrected-to-normal vision. All participants completed the Edinburgh handed inventory and used their dominant hand to point. One participant used their left hand, while four used their right hand.

Apparatus

An eye tracker and a touch screen monitor were used to record data during the experiment. Stimuli were presented on the touch screen, which was a 17-inch ELO touchscreen monitor with a resolution of 1024x768 pixels and a screen refresh rate of 85 Hz. The eye tracker was a SR Research Eyelink 1000, which recorded eye position during the tasks. Eye position was sampled at 1000Hz with a spatial precision of 0.25°, according to the manufacturer's specifications. The experiment was run using custom software written in MATLAB using the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Prior to the experiment, the monitor's non-linear gamma function was corrected to be linear using a photometer.

Experimental equipment were set up on a desk. The eye tracker was mounted on the edge of the desk, and the touch screen monitor was 40 centimetres in front, raised by a wooden block to participants' eye level. A mouse and a keyboard were set up between the screen and the eye tracker for use during the experimental tasks. Participants sat at the desk with their head rested on the chin rest of the eye tracker for all blocks of experimental tasks.

A diagram of the experimental design is shown in Figure 1. The central fixation point is placed in the bottom centre of the screen and was 1° in diameter. The two targets (dark grey) are

10° from the central fixation point and were 2° in diameter. All seven light grey distractors were. also 2° in diameter; two, three, and two distractors are at eccentricities of 5°, 10°, and 15° from the fixation point, respectively. Distractors were 5° from their adjacent peers. The probe, as a dot of contrast within the distractors, were 0.2° in diameter.

As measured by the photometer, the background luminance of the screen was 67.8 cd/m^2; the luminance of the central fixation point was 1.6 cd/m^2; the luminance of the experimental task area was 61.5 cd/m^2; finally, the luminance of the distractors was 42.3 cd/m^2.

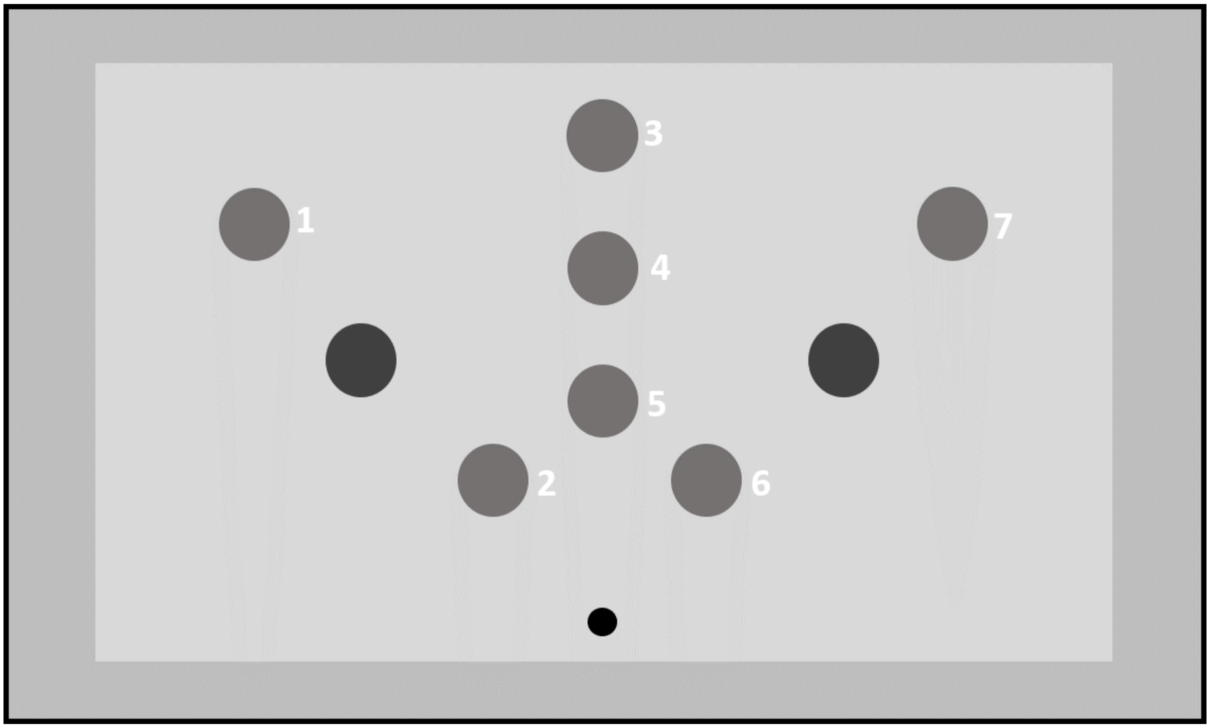

Figure 1. Diagram of experimental design. Black circle in the bottom centre is the central fixation point, while the unlabelled, dark grey circles are the targets. Circles labelled from 1-7 are all possible locations where the probe could appear.

Procedure

This study was approved by the University of Adelaide School of Psychology Human Research Ethics Committee (see Appendix A). The experimental design conditions take reference from Stewart and Ma-Wyatt's (2015) study, which was able to examine the spatiotemporal profiles of attentional facilitation for reaches and saccades independently by asking participants to maintain fixation in the reach-only condition or make a saccade + reach to the target. A comparison of these conditions allowed the isolation of the contribution of the reaching movement to attentional facilitation. The methodology of this experiment also draws from previous studies such as Rolfs and Carrasco (2012), which apply probes at predetermined threshold levels to determine the benefit in performance related to attentional shifts.

A repeated measures design was used – all participants completed all conditions. Prior to the experiment, participants read the experiment information sheet and gave their consent by signing the consent form. Participants were informed that they could withdraw from the experiment at any time and were asked whether they have any questions prior and after completing the experiment. After completing the baseline task to determine their threshold levels, participants completed the two experimental conditions, which contained 10 blocks each for a total of 20 blocks over the entire experiment. On average, the experiment was 4 hours in total. Participants typically completed two two-hour sessions over two days; in the first session, participants completed the baseline threshold tasks and one experimental condition, then completed the second experimental condition in the second session. The reach-only and saccade + reach conditions were counterbalanced, wherein three participants first completed the saccade + reach task, and two participants first completed the reach-only task.

Baseline. Participants were asked to firstly complete the baseline task to determine their threshold sensitivity. The design of the task involved a black fixation point at the bottom centre of the screen, and two grey probes equidistant from the fixation point on the left and right side of the screen at one of three eccentricities: 5°, 10°, and 15°. We did this to ensure that all three eccentricities were all equally detectable (e.g. Pointer & Hess, 1989), since contrast sensitivity scales as a function of eccentricity.

Participants were required to maintain fixation on the fixation point and press the spacebar to begin the trial. A tone sounded at the spacebar press to signal the beginning of the trial, at which point a dot appeared inside either one of the grey targets with equal probability as a contrast increment for 0.1 seconds. Participants were then required to press 1 on the number pad of the keyboard if they saw the contrast increment in the left target and press 3 if they saw the contrast increment in the right target. Using a QUEST paradigm set to 82% threshold level (Watson & Pelli, 1983), the contrast between the subsequent probe and the background target was decreased for a correct answer and increased for an incorrect answer. Each block of the task contained 40 trials, and participants completed two blocks for each eccentricity for a total of 80 trials per eccentricity, and 240 trials overall. Blocks were roughly 5 minutes each, and the baseline task overall was around 30 minutes.

After each block, the 82% threshold sensitivity value was estimated using QUEST and recorded. An average sensitivity value for each eccentricity was then calculated from results of the two blocks. These thresholds were used as the contrast sensitivities of the probes, respective to their corresponding eccentricity, for each participant.

Reach-only. The reach only task involved one central fixation point, two targets, and seven probe locations (Figure 2). Participants were asked to maintain fixation on the fixation point during the entire experiment. The task was run for 10 blocks in total. At the beginning of each block, a brief calibration was carried out for the eye tracker. The experimental task was run after calibration was completed. Participants rested their preferred hand on the mouse and clicked and held a mouse button to begin the trial. On each given trial, after the mouse press, there was a random delay of 0-500ms before cue onset. The cue was either a high or a low tone, which signalled the participant to release the mouse and reach and touch either the left or the right target, respectively. The probe was randomly presented at one of the seven locations, after a SOA delay of 100ms, 200ms, 300ms, or 400ms after presentation of the cue. The SOA was randomised from trial to trial, and each SOA was repeated twice for each target location in each block. After the target was touched, a screen appeared with only the seven probe locations, each assigned a number, and text that read “Where was the probe? Press the corresponding key on the number pad”. Participants then indicated the location at which they believed the probe appeared by pressing its corresponding number on the number pad of the keyboard. After the key press, the screen returned to the image at the beginning of the trial, and participants clicked and held the mouse to begin the next trial. In each block, the probe appeared once at every probe location (7), for every SOA (4), for both targets (2), and with two repeats in a random order for a total of 112 trials per block (7×4×2×2). Each block required 6-8 minutes; in general, participants completed the experimental task in two 5-blocks with a 30-minute break in between.

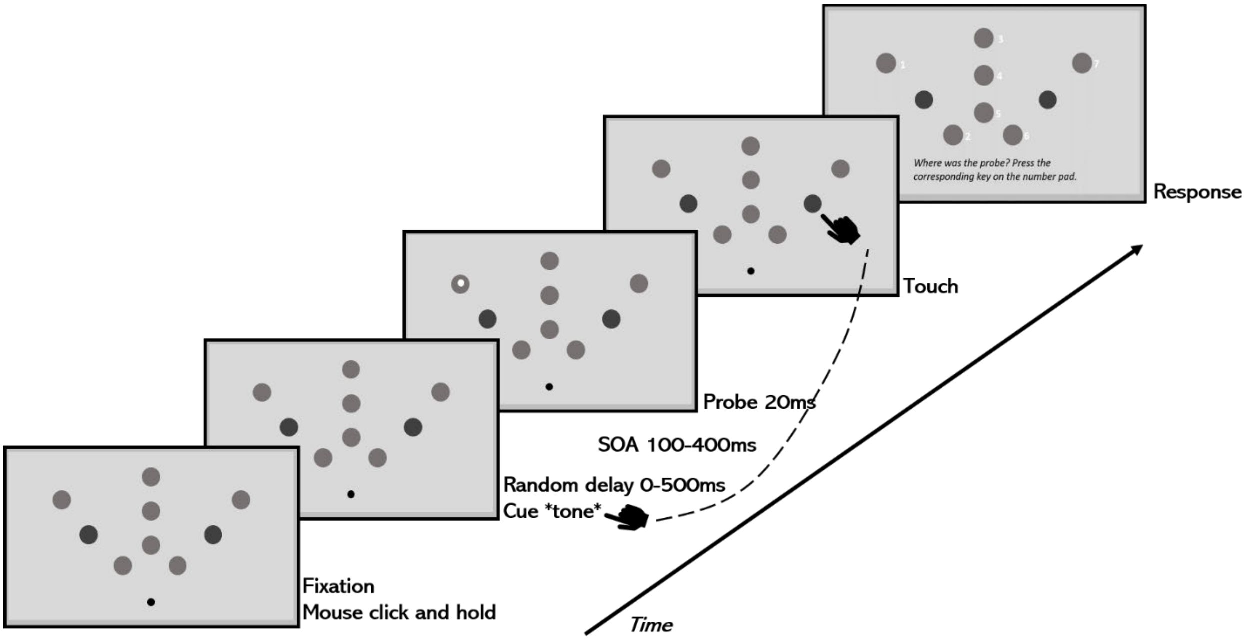

Figure 2. Reach only task procedure. The cue was either a high or a low tone corresponding to the left or right target, respectively. The probe (small white circle) could appear at any one of the seven locations.

Saccade + reach. The saccade + reach task followed exactly the same procedure as the reach-only task, except participants were asked to make a saccade as well as a reach towards the saccade. This is indicated by the simultaneous removal of the central fixation point at the presentation of the cue.

Results

Data Exclusions

Data were collated and processed using MATLAB. Trials in which the participant pointed to the wrong target were excluded, as were trials in which the saccade latency was less than 100ms in order to avoid anticipatory saccades that were not generated in response to the target (He & Kowler, 1989). Data analyses were carried out using R Studio. The percentage of trials retained for each participant, separately for the saccade + reach and reach-only 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.

	Saccade + Reach	Reach-only
Participant	Trials retained (%)	
P1	95.8	93.3
P2	48.1	80.6
P3	58.8	95.1
P4	69.1	87.7
P5	24.1	95.7

Descriptive Statistics

Descriptive statistics for the saccade latency, reach latency, and reach times for individual participants are presented in Table 2.

Table 2. Descriptive statistics for individual participants' average saccade latency, reach latency, and reach time (ms).

		Saccade + Reach		Reach-only	
		M	*SEM*	*M*	*SEM*
Saccade Latency	P1	449	6	--	--
	P2	205	3	--	--
	P3	195	2	--	--
	P4	170	5	--	--
	P5	231	5	--	--
Reach Latency	P1	617	6	619	7
	P2	491	4	595	10
	P3	532	8	592	3
	P4	532	107	620	11
	P5	563	23	578	11
Reach Time	P1	456	3	448	5
	P2	424	6	475	9
	P3	628	8	544	5
	P4	540	10	432	8
	P5	516	12	405	7

SOA

Data were collapsed across all target locations and probe locations to produce one set of data for analysis. A two-way analysis of variance (ANOVA) was run to examine the effects of SOA and experimental condition on attentional facilitation, which is represented by the proportion of correct responses made by the participants for contrast sensitivity (Figure 3). The first factor was SOA, with four levels of 100ms, 200ms, 300ms, and 400ms; the second factor was the experimental conditions, with two levels of saccade + reach and reach-only. Analysis shows no significant main effect of SOA on correct response rate, *F*(3, 12) = 2.29, *p* = .18, η_p^2 = .57. The main effect of experimental condition on correct response rate was not significant, *F*(1, 4) = 7.62, *p* = .05, η_p^2 = 1.91. The interaction between SOA and experimental condition on correct response rate was significant, *F*(3, 12) = 7.66, *p* =.004, η_p^2 =1.91. Four post-hoc contrast comparisons were conducted to unpack the significant interaction effect; a Bonferroni correction was used to account for the number of post-hoc comparisons made, so the alpha-value used was .0125. The significant interaction effect was revealed to be at SOAs of 300ms, t(10) = -3.78, *p* = .003 and 400ms, t(10) = -3.27, *p* =.008, respectively.

The overall profile of attentional facilitation for the reach-only condition remains fairly consistent across all SOAs, while it increases with longer SOAs for the saccade + reach condition, indicated by the increase in proportion of correct responses. A greater difference between the two experimental conditions in correct response rates is observed with longer SOAs, such that attentional facilitation becomes significantly greater in the saccade + reach condition than the reach-only condition for probe onset times of 300ms and 400ms post cue-onset.

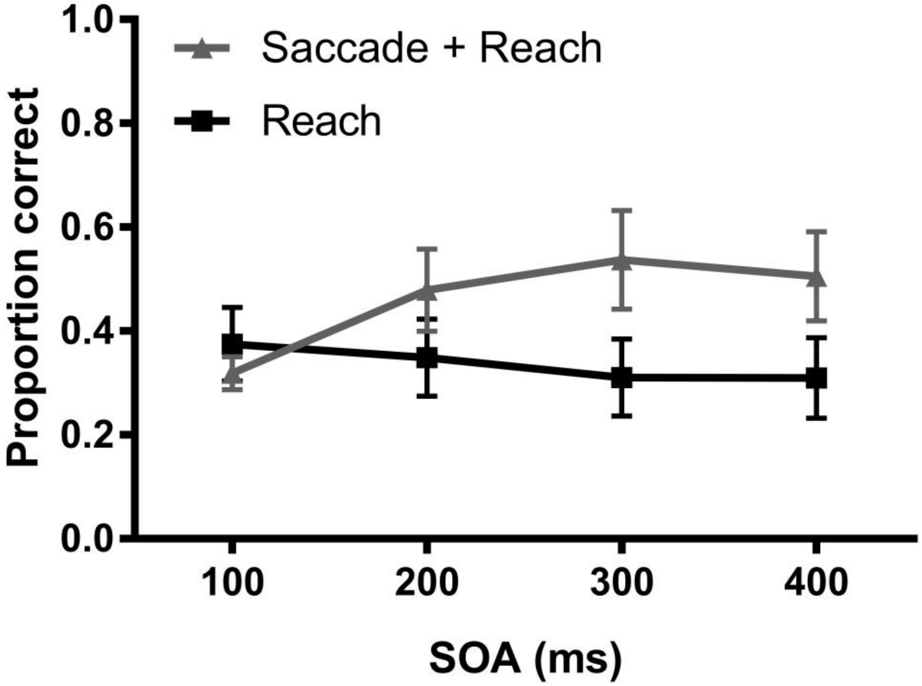

Figure 3. Mean correct response rates across SOAs for the saccade + reach and reach-only experimental conditions across all aprticipants. Error bars are SEMs.

Relative to saccade onset

Data were sorted into 100ms bins according to the time that the probe appeared relative to the saccade onset time to see how the planning and execution of a saccade affects the profile of attentional facilitation (Stewart & Ma-Wyatt, 2015). For instance, if in a trial the probe appeared 100ms before the onset of the saccade, the response for that trial would be placed into the -100ms bin. Trials were sorted into their respective bins using MATLAB on a trial-by-trial basis. In the end, data were sorted into 5 bins, ranging from -200 to 200ms in 100ms intervals (see Figure 4).

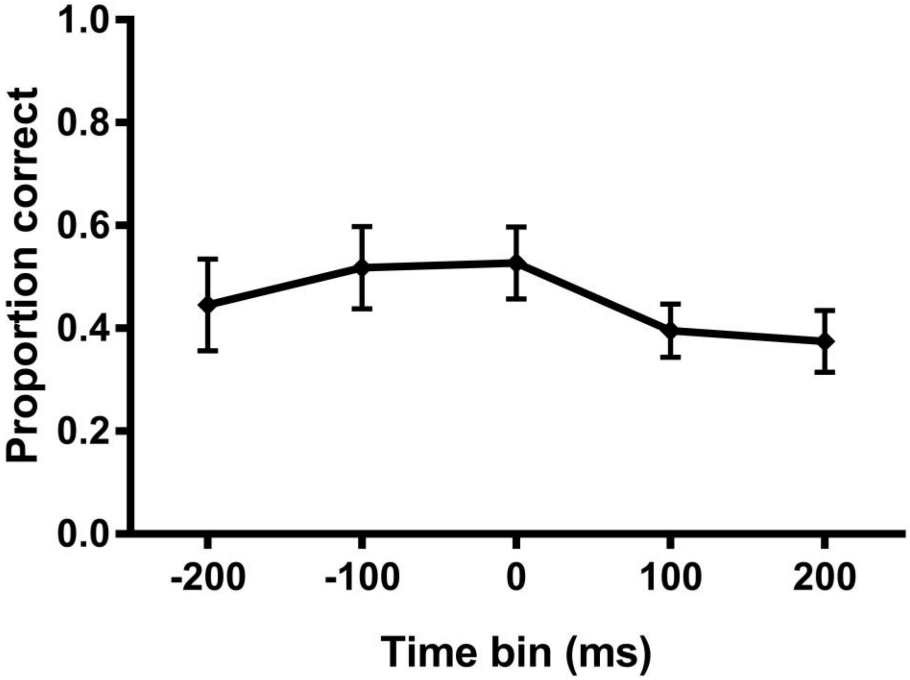

Figure 4. Mean correct response rates across all time bins relative to saccade onset (-200-200ms) across all participants. Error bars are SEMs.

A one-way ANOVA was run to examine the effects of time relative to saccade onset on on the proportion of correct responses made by the participants (Figure 4). The one factor, time relative to saccade onset, had five levels of -200ms, -100ms, 0ms, 100ms, and 200ms. Analysis revealed that the effects of time relative to saccade onset on correct response rates were not significant, $F(4, 20) = .93$, $p = .46$.

Relative to reach onset

Data were sorted into 100ms bins according to the time that the probe appeared relative to the reach onset time, separately for the reach movement data of the saccade + reach condition and the reach-only condition. Trials were sorted into their respective bins using MATLAB on a trial-by-trial basis. In the end, data were sorted into 4 bins ranging from 100 to 400ms in 100ms intervals. Figure 5 shows the means for all participants.

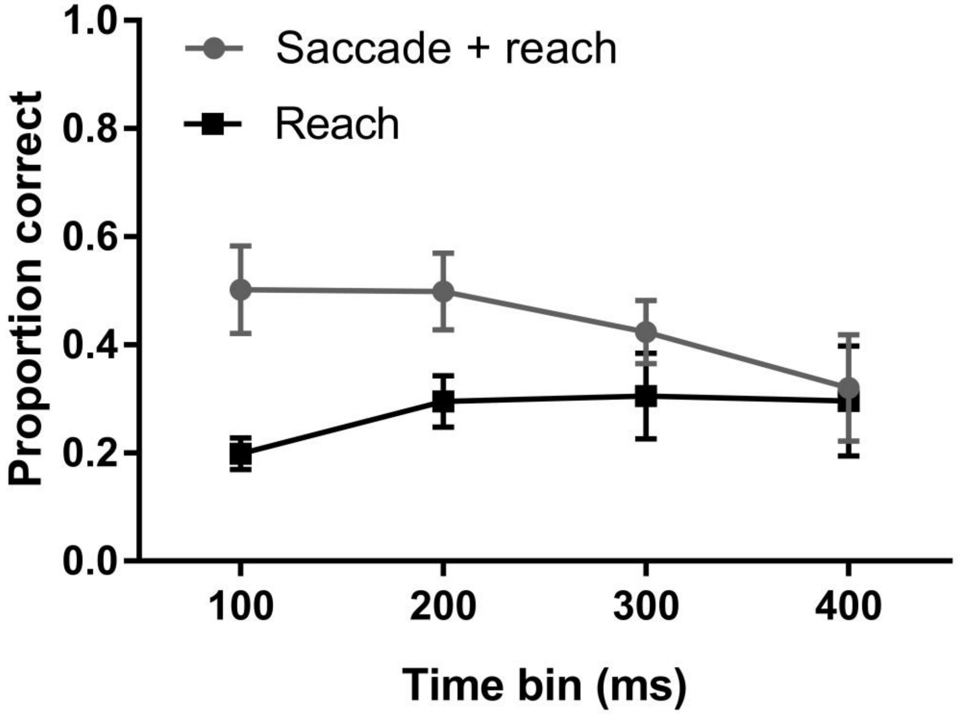

Figure 5. Mean correct response rates across reach latency time bins (100-400ms) for the saccade + reach and reach-only experimental conditions across all participants. Error bars are SEMs.

A two-way ANOVA was run to examine the effects of probe time relative to reach onset and experimental condition on attentional facilitation, as shown by the proportion of correct responses. Results showed no significant main effect of reach onset time, $F(3, 12) = .77$, $p = .53$, $\eta_p^2 = .19$. The main effect of experimental condition was significant, $F(1, 4) = 16.11$, $p = .02$, $\eta_p^2 = 4.03$. The interaction effect of reach onset time and experimental condition was also significant, $F(3, 12) = 6.27$, $p = .008$, $\eta_p^2 = 1.57$. Four post-hoc contrast comparisons were conducted to unpack the significant interaction effect; a Bonferroni correction was applied to correct the alpha-value by the number of comparisons made, to .0125. The significant interaction effect was revealed to be at reach latency times of 100ms, t(12) = -5.25, *p* = .0002 and 200ms, t(12) = -3.53, *p* = .004, respectively.

As can be observed in Figure 5, while there is no significant main effect of reach onset time; that is, points on the same line are not significantly different from one another, the difference in facilitation of attention between saccade + reach and reach-only conditions were significantly different overall and is observed to become smaller as reach latencies increase. Statistically, this is represented by the difference going from significant to non-significant with increase in reach latency.

Discussion

The present study was conducted with the aim to provide some insight into what the spatiotemporal profile of selective attention would look like during natural saccadic and reaching movements in the real world. An experimental design that contains multiple targets and probes was used as a basic simulation of the complex visual environment in nature. Involving more complex designs in selective attention research is a next step following previous studies that have used simpler designs with sparse visual scenes in order to see how well their findings can infer how people select objects from visual arrays that are filled with other irrelevant stimuli.

The hypotheses of this study were that there will be differences in the observed profiles of attentional facilitation, as operationalised by correct identification of the location of a contrast increment probe out of seven possible options in each trial, on the basis of SOAs, probe onset relative to saccade and reach onset times, and task requirements, which ask participants to detect the probe while performing either a saccade and a reach, or a reach alone.

Performance Relative to SOA

SOA is the delay in time between the presentation of the movement cue (high or low tones) and the onset of the probe. The variation of SOAs from 100ms to 400ms during the experiments was done in consideration of Stewart and Ma-Wyatt's (2017) finding that participants' performance in probe detection peaks at different SOAs between saccade + reach and reach-only conditions, perhaps owing to the stage of movement that is being performed at a shorter versus longer time lapse after cue onset and their corresponding pattern of attentional facilitation.

Results from the present experiments are generally consistent with previous findings. While the pattern of performance was not significantly different within, or between the saccade + reach and reach-only conditions, there was an interaction effect of SOAs and experimental conditions such that change in the pattern of performance was significant between saccade + reach and reach-only at longer SOAs.

The widening of the performance gap between the two experimental conditions with length of SOA (Figure 3) is in line with established findings on the processes of selective attention that underlie the preparation and duration of saccades and reaches. As illustrated in Figure 3, the performance difference is smaller between the two conditions at 100ms and 200ms SOAs, at which point the saccades and reaches are likely not yet initiated. As shown in Table 2, the movement latencies were on average 547ms after cue onset. An explanation for these similarities in performance refers to Abrams et al. (1990) and Land's (2009) conclusions of a similar target selection process that occurs in the periphery during the preparation of both saccadic and hand movements. That is to say, the small difference is possibly due to the deployment of attention being of a similar pattern across the saccadic and reaching movement at this stage. In turn, the larger, statistically significant differences in performance at the 300ms and 400ms SOAs likely correspond to the performing stage of saccadic and reaching movements, in which the shift in overt attention from the central fixation point to the target in the saccade + reach condition will benefit probe detection, in line with previous experiments showing that the concentration of attention with saccadic movements provide higher acuity of the visual scene and therefore better chances of detecting the probe (e.g. Kowler et al., 1995; Carrasco, 2011). Conversely, the lack of accompanying saccade in the reach-only condition will not bring attentional benefits.

Performance Relative to Movement Onset

Probe detection performance relative to movement onset was measured on account of recurring differences observed in attentional facilitation across onset times for both saccadic and reaching movements by Stewart and Ma-Wyatt (2015; 2017). Similar to studies by these researchers, the present experiment also compared performance relative to reach onset within and between the saccade + reach and reach-only conditions. Since previous results by Stewart and Ma-Wyatt (2017) found a similar pattern of performance between saccades made alone and saccades made with a reach, a saccade-only condition was not included in the present experiment. As such, probe detection performance relative to saccade onset was only compared within the saccade + reach condition.

Performance across reach onset times were not significant within conditions, which is consistent with the generally flat pattern of results from previous experiments (e.g. Stewart & Ma-Wyatt, 2017). Overall performance was significant between saccade + reach and reach conditions, as was performance across reach onset times when mediated by the saccade + reach and reach conditions. The gap in performance between the saccade + reach and reach conditions was significantly different when the probe appeared 100ms-200ms after reach onset but decreases to become non-significant at 300ms-400ms after reach onset (Figure 5). This pattern carries some similarities with previous experimental results by Stewart and Ma-Wyatt (2017) in that performance is observed to favour the saccade + reach condition at similar onset times. However, it is important to note that the time bins recorded between the two studies are different: the present study reported time bins of 100ms-400ms while Stewart and Ma-Wyatt (2017) reported time bins of -200ms-200ms; the researchers also observed that the temporal profile of attentional facilitation during a reach peaks before movement onset and tapers off during the reaching movement towards completion. While a comparison of performance cannot be made for probe onset times before reach onset, the tapering off of attention as the reaching movement progresses towards completion can explain why performance differences decrease with increase in probe onset time. The better performance in the saccade + reach condition can once again be attributed to perceptual benefits of the concurrent saccade to the target location alongside the hand movement (Kowler, 2011; Stewart & Ma-Wyatt, 2015; 2017) compared to a hand movement alone.

While probe detection performance was not significantly different across probe onset times relative to saccade onset, a better performance can be generally noted for saccadic movement over reach movement, once again supporting the perceptual benefits of overt selective attention with direct saccades (Kowler et al., 1995). Performance relative to saccade onset and reach onset were unable to be directly compared due to the different time bins that emerged for the two conditions.

Movement Latencies

Compared to single-target studies that have involved the same experimental conditions (Stewart & Ma-Wyatt, 2015; 2017), reach latencies were slower in the present experiment in both the saccade + reach and reach-only conditions and there is additionally a greater difference between hand-eye latencies in the saccade + reach condition. Based on latency values alone (Table 1), it would appear that participants are completing the saccadic movement first before making the reach. There are a number of possible explanations for this, including that participants are simply taking longer to react to the task cues. This is unlikely, however, since the saccade latency values of participants were similar to that recorded in single-target studies (e.g. Stewart & Ma-Wyatt, 2017) with the exception of Participant 1.

Another explanation is that participants are using strategies to prioritise tasks during the experiment. This may be more likely, since studies have found that factors such as perceived goals of the task and task difficulty can affect how attentional resources are allocated temporally along the action path (Baldauf & Deubel, 2010; Kowler, 2011). It is important to ascertain whether these observed strategies were voluntarily or involuntarily used by participants in order to further understand the factors that influence attentional facilitation and the degree to which prioritisation is a conscious or subconscious process.

Relevance to Field

While longer than that of single-target studies, the hand-eye latencies of the present experiment are comparable to results from Hayhoe et al.'s (2003) study of naturalistic behaviour, in which participants were tasked with making a sandwich and completed the task by selecting and using the necessary items, which were all placed in front of them on the same desktop. The concentration of hand-eye latency frequencies in Hayhoe et al.'s (2003) study were between 0ms and 400ms, with the highest frequency observed at 0ms. In comparison, the average hand-eye latency across participants in the present experiment was approximately 300ms. An important distinction between Hayhoe et al. (2003) and the present experiment is that in the former, participants were aware of their task goals prior to the start of the task while in the latter, participants received general instructions but did not know the specific goal (left or right target) until the cue tone was presented.

This difference may explain why such a high number of hand-eye movement units were able to be produced with a 0ms latency in the Hayhoe et al. (2003) study. As explained by the researchers, a clear awareness of the task objective allows movements to be prepared for speedier action. Even so, the overall distribution of hand-eye latencies was spread across a span of up to 950ms. This can imply that even when given ample time to prepare movement, complexity of the visual landscape can still produce variations in hand and eye movement patterns. The similarly longer hand-eye latencies recorded for the present visual layout design is therefore a testament of its value as a representation of visual scene complexities in the natural world. Latency differences compared to single-target studies also provide support for the need to explore established findings about the facilitation of selective attention using designs with more complex visual arrays.

Limitations

A potential limitation of the present experiment is the variance in the number of trials retained for each participant. All participants had completed 10 blocks of each condition with the aim of collecting around 1000 valid trials, comparative to the number of trials used in previous experiments with similar aims and task designs (e.g. Stewart & Ma-Wyatt, 2017). Unexpectedly, the error rates were quite high, which resulted in a high percentage of trial exclusions with the exception of Participant 1, especially for the saccade + reach task. More data were not collected to compensate for the excluded trials due to time constraints but doing this in the future may have the benefits of reducing variance within participants.

Another potential improvement to the present experimental procedure could be to separately analyse probes and targets of different locations. The present experiment had collapsed data across all target and probe locations because the baseline task ensured that all probes were equally visible, and the high attrition rates also did not make it viable to test locations individually. Future studies that analyse probe locations and eccentricities separately can assess the accuracy of the equal-visibility assertion and explore whether there is an effect of distance from the target even when probes are made to be equally visible.

The high exclusion rates may in themselves imply that increasing the complexity of the visual scene can affect task performance in probe detection; therefore, perceptual performance for simple visual arrays may be unable to predict performance in scenarios involving more complex arrays. With additional consideration of movement latencies, especially the fact that

Participant 1 has the longest average saccade and reach latencies but the least number of error trials, it may also be suggested that slower movements are implicative of a different pattern of attentional facilitation across time and space that enables the accurate performance of task instructions.

Future Steps

Some improvements to the current experimental procedure, aside from obtaining a more balanced number of valid trials across participants, is to provide more specific task instructions and explore whether placing an emphasis on reach or perceptual accuracy will change participants' movement latencies and probe detection performance. This can provide an insight into whether the prioritisation of attentional resources to different aspects of an action task is a conscious or subconscious process.

Expansions to the present experimental design can involve the addition of different visual features, such as texture or colour, to the current design. Texture has been shown to affect the spread of attentional facilitation across the visual field during saccades (Ghahghaei & Verghese, 2017), while colour is shown to activate a different attentional resource pool than luminance contrast (Morrone et al., 2002). The interactions of these visual features in a more complex visual array and their effects on the spatiotemporal profile of attentional facilitation can be a further step in simulating a more realistic visual field in the laboratory setting.

Asking participants to perform movement sequences and saccade or reach to multiple points across the visual layout can also allow the exploration of temporal immediacy and task demands on the facilitation of selective attention across a complex visual field, since they have previously been found to affect perceptual performance during movement sequences in simpler designs (Baldauf & Deubel, 2009; 2010).

Conclusion

In conclusion, similar to previous findings using simpler design layouts (e.g. Stewart & Ma-Wyatt, 2015; 2017), the present experiment reports benefits to perceptual performance for the involvement of saccade + reach compared to a reach alone across a complex visual layout involving multiple targets and distractors. Specifically, similar effects of perceptual benefits to probe detection performance were found for the saccade + reach condition over the reach-only condition for SOAs and probe onset relative to reach-movement onset at similar points in onset time. The smaller variation in performance across the SOA as well as a greater discrepancy between saccade and reach latencies imply that visual scene complexity has an effect on performance, highlighting the importance of replicating the natural visual field in future explorations of selective attention.

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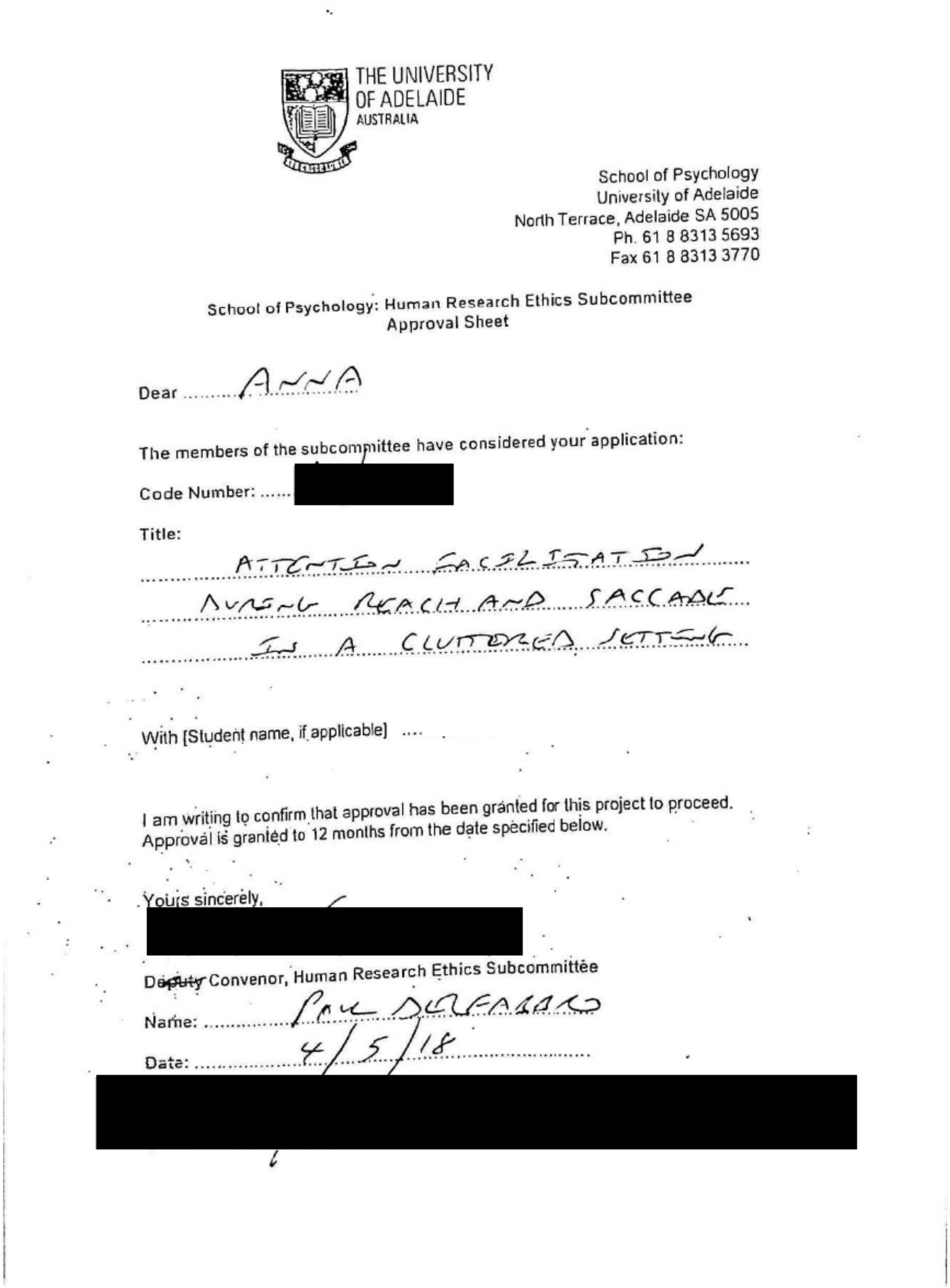
Appendix A – Ethical Approval



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

The members of the subcommittee have considered your application:

Code Number: [redacted]

Title:
ATTENTION FACILITATION
DURING REACH AND SACCADE
IN A CLUTTERED SETTING

With [Student name, if applicable] ....

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: PAUL DELFABBRO

Date: 4/5/18

[redacted]

Appendix B – Participant Information Sheet

THE UNIVERSITY of ADELAIDE

Participant information sheet

Project Title: attentional facilitation in reaching and saccades in a cluttered setting

Principal Investigator:

Supervisor Researcher: A/Prof Anna Ma-Wyatt

Welcome,

You have been invited to participate in the research project which is in relation to my Honours thesis. The research will be conducted at the University of Adelaide by myself, Yinhong Ouyang, under the supervision of Associate Professor Anna Ma-Wyatt.

What is the project about?

In everyday scenarios when we reach or look towards a target, it will usually be surrounded by other objects as well. We will be investigating how visual attention is facilitated when attending to a target in a cluttered setting in order to study the spread of visual attention in a more naturalistic setting.

Why am I being invited to participate?

We are seeking healthy adults to participate in the experiment at the University of Adelaide. Participants should have normal or corrected to normal vision and have no history of eye complications.

What will I be asked to do?

Participants will be required to reach, make a saccade, or reach and make a saccade towards a target that is set amongst probes of various locations within an area. During the action process, there will be a contrast increment at one of the random probe locations, which participants will be asked to report about after the completion of the trial. A mounted eye tracker and hand trackers attached to the participant's hand will record eye and hand movement trajectories during each trial. The experimenter will be present throughout the duration of the study and will be happy to answer any questions during the experiment, as well as to offer a debriefing after the conclusion of the experiment if you require any more information concerning the experiment and project.

Are there any risks involved with participating in this study?

You may experience some visual fatigue, similar to that that may accompany staring at a computer screen for extended periods of time. You will be provided with regular breaks throughout the experiment to ensure you do not experience such fatigue. Your participation in this study is voluntary and if you agree to participate, you are free to withdraw at any time without consequence.

What are the benefits of the study?

The results of this study will provide important insight into the facilitation of visual attention in a more naturalistic environment.

What will happen to my information?

All data and information collected will be treated confidentially and will be secured on password-protected computers that will only be accessed by the experimenters. If the data acquired from the experiment is used in publications, then measures will be taken to de-identify individual participants.

Who do I context for more information or if I want to participate?

Please contact myself, for more information.

For any questions concerning the ethics of this project, please contact the convener of the Subcommittee for Human Research in the School of Psychology, Dr. Paul Delfabbro, 08 313 4936

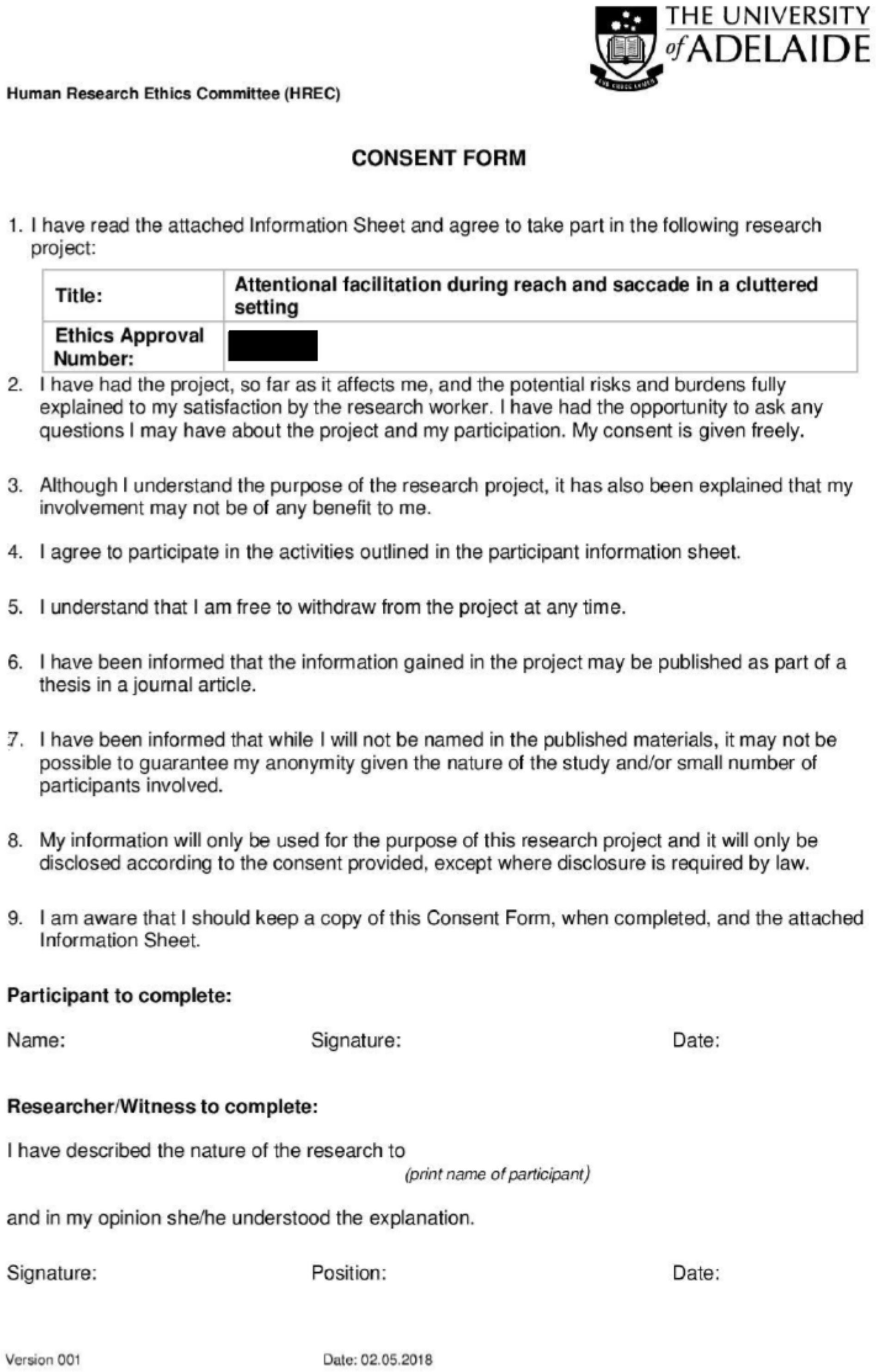
Yours Sincerely,

School of Psychology

University of Adelaide

Email: @student.adelaide.edu.au

Appendix C – Consent Form



THE UNIVERSITY *of* ADELAIDE

Human Research Ethics Committee (HREC)

CONSENT FORM

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

Title:	**Attentional facilitation during reach and saccade in a cluttered setting**
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 as part of a thesis in a journal article.

7. I have been informed that while I will not be named in the published materials, it may not be possible to guarantee my anonymity given the nature of the study and/or small number of participants involved.

8. My information will only be used for the purpose of this research project and it will only be disclosed according to the consent provided, except where disclosure is required by law.

9. 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 001 Date: 02.05.2018