A Journey Through Time and Space: The Spatiotemporal Profile of Attention Relative to Saccade and Reach

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ABSTRACT

In an interactive environment, we use a multitude of eye and hand movements to gather information about our surroundings, and to act upon what we see. While these are the eventual, overt behaviours that we observe, there are countless hidden neural processes guiding where we move our eyes and hands. This thesis will examine one such of these processes: visual attention. Visual attention has been shown to produce perceptual benefits, such as an increase in contrast sensitivity, at the attended location, and there is evidence that before an eye or hand movement is made, attention shifts to the location of that upcoming movement target. This thesis aimed to comprehensively map the spatiotemporal profile of attention when reaches and saccades were being planned and executed, in order to compare how attention shifts when different types of movements are being made.

The first experiment mapped the spatiotemporal profile of attention relative to a reach alone. Results of this study showed that when a reach alone is being planned, there is a broad spatial allocation of attention across the visual field, while the temporal profile shows a slight increase before the onset of a reach, with a dramatic drop in performance once the hand is in flight. The second experiment compared the spatiotemporal profile of attention for saccades alone, and saccades with a concurrent reach. These results, in contrast showed a large increase in performance before the start of a movement, and a plateau of performance during the movement itself. The third experiment aimed to explore how attention may differ depending on where a probed location is situated relative to the direction of a movement, and to compare how this may change across different movement effectors. Results showed that the profile of attention differed depending on both movement effector and whether the probe appeared in line with or orthogonal to the direction of a movement. These results also suggest that attention spreads differently when a saccade is being made, irrespective of whether a reach is being conducted or not.

Overall, the results of this thesis showed three main effects: the spatiotemporal profile of attention is different when a saccade is being made compared to a reach alone; attentional facilitation at the location of a probe is different depending on where the probe is located, relative to the direction of movement; and this profile of attention varies depending on the type of movement being enacted. Additional results also suggest that attention may act in a dual facilitatory/inhibitory manner, depending on the movement effector. Taken together, these results provide evidence that different types of movement planning may require different levels of attentional guidance, and also provide evidence that pre-movement attention may be a flexibly allocated resource, depending on the demands of the task, and the movements being enacted.

DECLARATION BY AUTHOR

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ABBREVIATIONS (IN ORDER OF APPEARANCE)

EEG	Electroencephalography
LIP	Lateral intraparietal cortex
2AFC	Two alternative forced choice
FEF	Frontal eye fields
ERP	Event related potential
PPC	Posterior parietal cortex
VAM	Visual Attention Model
SFA	Selection for Action theory
SC	Superior colliculus
fMRI	Functional magnetic resonance imagery
IPS	Intraparietal sulcus
SOA	Stimulus onset asynchrony
RSVP	Rapid serial visual presentation
PRR	Parietal reach region
PMC	Premotor cortex
PMv	Ventral part of premotor cortex
MI	Primary motor cortex

SUMMARY OF THESIS

This thesis is comprised of three research chapters in the form of manuscripts prepared for publication, a literature review and a general discussion. The overall aim of the research contained within this thesis is to explore the spatiotemporal profile of visual attention when a saccade and/or reach is being planned and executed. Chapter 2 is a manuscript that has already been published in the *Journal of Vision*. Chapters 3 and 4 are manuscripts that have been prepared for publication. Chapter 5 summarises the results and provides a discussion and comparison of the experimental findings, and the implications for future research.

A note on terminology: unless included in the title of a paper (for example in Chapter 3), the term "pre-movement" will be used to describe pre-motor attention, in order to disambiguate any incidental usage from the "Pre-motor theory of attention" which is also discussed at various points throughout this thesis.

CHAPTER 1: LITERATURE REVIEW

This chapter provides an overview of the current literature surrounding visual attention and the interaction between vision, action and attention. The overview starts with a discussion of visually guided action, and how vision is important for planning movements in a visually rich, interactive world. Subsequently, there is a broader discussion of the problem of target selection in a visually rich environment, and a brief discussion of some of the current theories that explain how people may use salience maps, priority maps, and attention to focus on particular features in a scene. The major part of the literature review focusses on visual attention, and the interaction between attention and action, which is the main focus of this thesis. Finally, there is an outline and discussion of the relationship between attention, eye movements and hand movements, in both psychophysical/behavioural terms and neurophysiological terms.

Chapter 2: The spatiotemporal profile of attention relative to a reach

This manuscript uses psychophysical techniques to comprehensively map the spatial and temporal profile of visual attention relative to a goal-directed movement alone, without an accompanying saccade. This experiment aimed to determine how attention may shift across the visual field while a hand movement was being planned and executed, which provides an insight into how attention might be used to guide and facilitate manual movements. A novel experimental paradigm was used to measure attentional facilitation at six locations and nine time-points during a reach to a visual target. The main conclusions of this study were that attention increases and then is sustained during the preparation of a reach, and deteriorates as the hand nears the reach end-point. This study also suggests that the spread of attention may differ depending on the target location relative to the direction of the reach.

Chapter 3: Dissociating the premotor attentional shift for saccades and reaches

This chapter focuses on the spatiotemporal characteristics of visual attention when a concurrent saccade and reach are being made, compared to when a saccade alone is being executed. This study demonstrates how planning a saccade alone compared with planning a saccade and concurrent reach affects when and where attention is allocated, allowing insight into how attention may play a role in saccade and reach planning. The paradigm was a modification of the paradigm used in Chapter 2, to allow for general comparison of results. This study showed that the pre-movement attentional shift happened on a similar timescale when a reach was being planned with a saccade, compared to the saccade alone, and the shape of the function was also similar. This suggests a unified attentional resource guides movements in the presence of a saccade.

Chapter 4: The profile of attention differs at locations orthogonal to reach direction

This chapter aims to resolve the pattern of results seen in Chapter 2 by exploring the effect of reach direction on the attentional profile at locations either in line with, or orthogonal to the direction of either a reach alone, saccade alone, or a concurrent reach and saccade. The main conclusions suggest that there is a difference in the attentional profile at locations orthogonal to reach direction, and this differs depending on the movement being enacted. Similar results have only before been found when exploring the peri saccadic remapping process. The results also suggest that the spatiotemporal profile of attention is malleable, depending on the paradigms and demands of a task. This experiment also provides further evidence that that some areas of the visual field surrounding a target may be subject to attentional inhibition as well as facilitation.

Chapter 5: Discussion

This chapter amalgamates the findings from the three substantive experimental chapters and discusses these results with a comparison to previous research in the area, and in the context of current predominant theories of pre-movement attention. The major crux of this thesis – how enacting different types of movements may affect the spatiotemporal profile of attention – will be discussed in depth, and in particular this section will explore both reasons why the saccade seems to dominate this attentional profile, and why attention accompanying a reach without a saccade follows such a different time-course. Secondary issues that have arisen from the experiments will also be considered, such as the idea of attentional inhibition. These topics will be discussed in terms of both psychophysical evidence, and links will be drawn to possible underlying neurophysiological mechanisms.