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A fresh look at saccadic trajectories and task irrelevant stimuli: Social relevance matters

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ABSTRACT

A distractor placed nearby a saccade target will cause interference during saccade planning and execution, and as a result will cause the saccade's trajectory to curve in a systematic way. It has been demonstrated that making a distractor more task-relevant, for example by increasing its similarity to the target, will increase the interference it imposes on the saccade and generate more deviant saccadic trajectories. Is the extent of a distractor's interference within the oculomotor system limited to its relevance to a particular current task, or can a distractor's general real-world meaning influence saccade trajectories even when it is made irrelevant within a task? Here, it is tested whether a task-irrelevant distractor can influence saccade trajectory if it depicts a stimulus that is normally socially relevant. Participants made saccades to a target object while also presented with a task-irrelevant (upright or inverted) face, or scrambled non-face equivalent. Results reveal that a distracting face creates greater deviation in saccade trajectory than does a non-face distractor, most notably at longer saccadic reaction times. These results demonstrate the sensitivity of processing that distractors are afforded by the oculomotor system, and support the view that distractor relevance beyond the task itself can also influence saccade planning and execution.

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1. Introduction

When a rapid eye movement, or saccade, is made towards a target, the path that the saccade takes is often slightly curved (Viviani, Berthoz, & Tracey, 1977; Yarbus, 1967). The magnitude and direction of this curvature can be influenced by the presence of nearby non-target objects. Relevant (Sheliga et al., 1995; Sheliga, Riggio, & Rizzolatti, 1994, 1995) or even task-irrelevant (Doyle & Walker, 2001; McSorley, Haggard, & Walker, 2004; Van der Stigchel & Theeuwes, 2005) non-target objects that are presented near a saccade's goal can change the curvature of a saccade in systematic ways. At its core, a saccade's trajectory can be interpreted as reflecting target selection and distractor inhibition within the oculomotor system. By examining what features of a target or a distractor influence a saccade's trajectory, one can infer what stimulus properties are prioritized or are considered salient by the oculomotor system during target selection and saccade planning.

In general, a distractor whose features attract attention will influence the trajectory of a saccade aimed to a nearby target (e.g. Nummenmaa, Hyönä, & Calvo, 2009; Theeuwes & Van der Stigchel, 2009; Van der Stigchel, Mulckhuyse, & Theeuwes, 2009). To explain this behavioral effect, it is often assumed that in the oculomotor system, likely at the level of the midbrain superior colliculus (SC), a priority map represents attended objects based on their low-level saliency and their goal-related relevance (Fecteau & Munoz, 2006; Godijn & Theeuwes, 2002; McSorley, Haggard, & Walker, 2004). Each attended location or object is represented by a population of neurons that encode a movement vector to the target. The greater the object's combined salience (for example, strong stimulus intensity; Bell et al., 2006) and relevance (e.g. its similarity to a target object, Ludwig & Gilchrist, 2003; or proximity to the goal, McSorley, Cruickshank, & Inman, 2009), the stronger its initial activation will be upon the priority map. Populations representing separate but nearby objects will overlap within the map, shifting the overall activity distribution to generate a weighted vector average based on the strength of their respective activation. The result is a saccade whose trajectory represents a combination of that which would be generated in response to the presentation of either the distractor or the target in isolation. Saccade accuracy can be improved through active enhancement of the target's

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representation, and possibly through inhibition of the non-target representation (thought to be accomplished either by top-down inhibition, Al-Aidroos & Pratt, 2008; Van der Stigchel, 2010; Walker, McSorley, & Haggard, 2006, inhibitory projections from the substantia nigra, White, Theeuwes, & Munoz, 2012, or through lateral interactions within the SC itself, Wang, Kruijne, & Theeuwes, 2012). According to some inhibitory accounts, it is thought that as time passes, inhibition to the distractor shifts the overall activity within the priority map such that peak activity is further away from the distractor's true location, which results in a saccade that initially deviates away from the target and the distractor's locations (Van der Stigchel, Meeter, & Theeuwes, 2006).

To date, the study of saccadic trajectories has primarily relied upon within-task manipulations of simplistic target and distractor stimuli in order to manipulate the relative priority of the distractor to the participant. For example, a distractor can be made more relevant by either directly requiring participants to attend to it in order to determine the saccade goal (e.g. Sheliga, Riggio, & Rizzolatti, 1995), or by making it more similar to the target (e.g. by sharing its color, Ludwig & Gilchrist, 2003, or shape, Mulckhuyse, Van der Stigchel, & Theeuwes, 2009). Studies of this kind have established that saccade trajectories are more strongly affected by the distractor when it is arbitrarily made relevant for an experimental task. If, however, the overarching goal of this line of research is to establish how the oculomotor system behaves in everyday life, then one (of many) important avenues to explore is whether trajectory modulations can be observed in response to distractors whose relevance is defined more broadly than just within the task itself. The present studies examine whether a distractor that is inherently meaningful, not just within the task-at-hand but in everyday life, can elicit stronger trajectory deviations when compared to a distractor which lacks that general relevance but shares the same low-level visual properties. To test this, images of faces and unrecognizable scrambled faces were used as distractor stimuli. Both stimuli were task irrelevant, but while the former is socially relevant outside the paradigm itself, the latter is not.

Social stimuli were chosen as a test of whether the oculomotor system is sensitive to task-irrelevant distractor relevance primarily because of the strong evidence that faces are treated as relevant social stimuli in other paradigms. Even from early infancy, people pay special attention to faces over non-face stimuli (Farroni et al., 2005; Johnson et al., 1991; Mondloch et al., 1999). Faces, especially when presented upright, have been shown to attract (Devue, Belopolsky, & Theeuwes, 2012; Langton et al., 2008; Theeuwes & Van der Stigchel, 2006) and hold attention (Bindemann et al., 2005), and are detected over non-face stimuli, even under difficult viewing conditions (Devue et al., 2009; Mack et al., 2002). This attentional bias to attend to faces may be in part due to their strong activation of specialized face areas such as the fusiform gyrus (or fusiform face area, FFA; Kanwisher, McDermott, & Chun, 1997; McCarthy et al., 1997; Rhodes et al., 2004). Even in more unconstrained viewing conditions, faces are looked at more often than would be expected based on their low-level saliency (Birmingham, Bischof, & Kingstone, 2009), and demonstrate their social relevance by acting to guide attention to other relevant features in a scene (Castelhano, Weith, & Henderson, 2007). Note, however, that this evidence of strong prioritization of faces does not necessarily predict that within the oculomotor system, representations of task-irrelevant social stimuli are enhanced upon the priority map (e.g. would cause greater interference within a saccadic trajectory paradigm). The advantages for face vs. non-face stimuli may stem from privileged processing at other levels, for example at the FFA or superior temporal sulcus, and this information may or may not be easily accessible during saccade planning and execution. Thus, that faces are treated as a special, socially relevant stimulus in other tasks makes them an ideal test case for determining whether oculomotor planning is also affected by relevance that is not defined by the task itself.

A handful of trajectory-based studies have diverted from using simplistic target and distractor stimuli (e.g. basic geometric shapes, lines), though only a small number have used images of faces, the majority of which employed the face as a central attentional cue rather than as a distractor (Hermens & Walker, 2010; Nummenmaa & Hietanen, 2006; West et al., 2011). Thus, as in many other non-trajectory tasks, the face is the focus of attention, and therefore these studies cannot be used to speak to whether task-irrelevant social stimuli influence oculomotor planning. However, in one of the few studies where faces were used as peripheral distractor stimuli, only faces which displayed threatening emotional expressions elicited stronger saccadic trajectories when compared to non-face stimuli (Schmidt, Belopolsky, & Theeuwes, 2012). In other words, emotional (especially threat-based) salience, *not* social faces more generally, affected saccade trajectories, possibly due to a direct fast connection between the amygdala and superior colliculus (LeDoux, 1996). Given the literature reviewed above demonstrating that faces are generally prioritized by the attentional system at other levels of processing, Schmidt et al.'s implicit conclusion – that the social relevance of faces bears no influence within the oculomotor system – is worth further exploration. If true, then these results imply that both the oculomotor system's ability to process the social relevance of a given distractor, and its sensitivity to influences of social relevance found elsewhere in the brain, are highly constrained.

However, to propose that the oculomotor system is insensitive to social stimuli based on the null results of Schmidt, Belopolsky, and Theeuwes (2012) could be premature. Despite their finding that a neutral distracting face did not influence saccade metrics, there are several reasons why general face (and by extension, social) information may still be prioritized by the oculomotor system. First, the authors report average trajectory deviations, yet it is known that deviations change across saccadic reaction times (SRTs), with greater deviation away from the target and distractor at longer SRTs (McSorley, Haggard, & Walker, 2006). As such, it may be that a face-based effect was averaged out when trials were collapsed across all response times. Alternatively, Schmidt and colleagues may have failed to find an effect of the neutral face distractor on trajectory because the time period they examined was suitable for detecting fast subcortically generated effects, but was too short to observe cortically mediated social relevance effects. Further, the relevance of a face stimulus may be manifested not as an initial boost in the distractor's representation, but as a perseverance of the signal overtime, consistent with findings demonstrating that faces hold attention to their location (Bindemann et al., 2005). This information could be difficult to observe if longer time periods were not examined separately.

In the present paper, findings are presented from two studies that together demonstrate a significant influence of a social stimulus – a distracting face – on saccadic trajectory. These results run contrary to what could be concluded from existing trajectory literature and suggest instead that the social relevance of a face is influential in oculomotor planning and execution. In Study 1, upright faces, which are known to engage many processes unique to face processing, were tested for their ability to cause greater saccade deviation when compared to inverted face distractors. In Study 2, the results of Study 1 are compared to findings using scrambled versions of the face stimuli used in Study 1 in order to determine whether faces, regardless of their orientation, might be prioritized within the oculomotor system over meaningless color- and luminance-matched objects. Both studies expand on previous work in two ways. First, they provide a detailed analysis of saccadic trajectory effects at various SRTs, exploring whether previous face-based

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