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# The effects of saliency on manual reach trajectories and reach target selection

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ABSTRACT

Reaching trajectories curve toward salient distractors, reflecting the competing activation of reach plans toward target and distractor stimuli. We investigated whether the relative saliency of target and distractor influenced the curvature of the movement and the selection of the final endpoint of the reach. Participants were asked to reach a bar tilted to the right in a context of gray vertical bars. A bar tilted to the left served as distractor. Relative stimulus saliency was varied via color: either the distractor was red and the target was gray, or vice versa. Throughout, we observed that reach trajectories deviated toward the distractor. Surprisingly, relative saliency had no effect on the curvature of reach trajectories. Moreover, when we increased time pressure in separate experiments and analyzed the curvature as a function of reaction time, no influence of relative stimulus saliency was found, not even for the fastest reaction times. If anything, curvature decreased with strong time pressure. In contrast, reach target selection under strong time pressure was influenced by relative saliency: reaches with short reaction times were likely to go to the red distractor. The time course of reach target selection was comparable to saccadic target selection. Implications for the neural basis of trajectory deviations and target selection in manual and eye movements are discussed.



## 1. Introduction

Efficiency in human vision and action is influenced by stimulus-salience. Objects that stand out from the surrounding objects can automatically draw attention and consequently can be found much more easily than objects that are not unique and conspicuous. For example, think about looking for the full moon on a clear night, the goalkeeper in a soccer team, or a single red tulip in a field of yellow tulips. Whereas stimulus-salience can benefit visual selection if it is in line with the search goal of an observer, stimulus-salience can harm performance if it concerns an irrelevant distractor object; e.g., the moon can interfere with search for a star, the goal-keeper distract search for a specific defender and a red tulip delay selection for a certain yellow tulip. Experimental evidence for this has been found in studies of covert attention (Theeuwes, 1992, 1994; Yantis & Jonides, 1984) as well as in studies of overt visual selection. In overt visual selection stimulus-salience has been demonstrated to affect performance in saccadic eye movements (Godijn & Theeuwes, 2002; Theeuwes, Kramer, Hahn, & Irwin, 1998; van Zoest & Donk, 2006), saccadic trajectories (Godijn & Theeuwes, 2004; van Zoest, Donk, & Van der Stigchel, 2012; Walker, McSorley, & Haggard, 2006) as well as manual pointing movements (Kerzel & Schonhammer, 2013; Song & Nakayama, 2006; Welsh, 2011; Welsh & Elliott, 2004; Wood et al., 2011; Zehetleitner, Hegenloh, & Muller, 2011).

Visual saliency is thought to be represented in maps where objects compete for attention (Itti & Koch, 2001; Yantis, 2005) or more generally for behavioral priority (Baldauf & Deubel, 2010; Fecteau, Enns, & Kingstone, 2000). Critically, evidence suggests that the representations in priority maps changes as a function of time (Donk & van Zoest, 2008). This has been demonstrated in studies of covert attention (e.g., Donk & Soesman, 2010), saccadic selection (van Zoest & Donk, 2006; van Zoest, Donk, & Theeuwes, 2004) and in saccadic trajectories (van Zoest et al., 2012).

In the present study, we examine whether this dynamic competition between target and distractor is also revealed in the curvature of the reach trajectories and in the final endpoint selection of the reaching movements. Previous studies on reaching provide support for facilitation of selection by salient targets and disruption of selection by salient distractors, but have not investigated the time-course of facilitation and disruption simultaneously.

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### 1.1. Saliency in manual reaching

Evidence suggests that the efficiency of reaching movements increases with target saliency. For example, in a study by Zehetleitner et al. (2011) participants were instructed to reach a feature singleton in a search array on a touch screen. The feature singleton was either defined by luminance contrast, by orientation, or by both luminance and orientation contrast. The results showed that initiation times, total movement duration time as well as pointing accuracy were better for targets with high than for low feature contrast, and improved even further when targets were redundantly defined (i.e., targets combining two features).

Whereas salient targets can provide a benefit in manual reaching performance, salient distractors may result in a detriment in performance. Kerzel and Schonhammer (2013) provided evidence that reaches deviate toward salient distractors. They presented a search display when the reach response had already been initiated, forcing participants to decide where to reach while the movement was ongoing. Reach trajectories deviated toward the salient distractor, showing that competition between target and distractor in a visual search display is reflected in reach trajectories. While deviation toward a distractor was observed in this study, its saliency was not manipulated systematically. Instead, the distractor was always a red bar and the target was a tilted bar on a raster of vertically oriented bars. Thus, it is not clear whether a more salient distractor would more strongly attract reaching trajectories.

Further, Wood et al. (2011) found that salient distractors influence reaching behavior even in the absence of direct competition with the target. In their study, the start signal consisted of a beep and distractor stimuli. The distractors were presented on the left and right of fixation and varied in saliency. The start signal prompted participants to release the home button within 325 ms, and the target appeared only once participants had initiated the reaching movement. The target appeared on the left or right and had to be touched. The authors observed that the initial trajectories were biased towards the side of fixation that contained the more salient distractors despite that the distractors were presented before movement and target onset. The results moreover showed that a preview of 500 ms eliminated this saliency-induced bias.

### 1.2. Dynamic representations in performance

Psychophysical studies suggest that the impact of stimulus-saliency on performance is severely limited in time (Donk & Soesman, 2010, 2011; Donk & van Zoest, 2008). This work shows that saliency affects perceptual performance only when selection occurs very shortly after display presentation. Further support for the transient nature of stimulus saliency is provided in studies on overt saccadic selection. For example in a study by van Zoest and Donk (2005), participants were instructed to make an eye movement to an orientation singleton (i.e., a line tilted to the right) presented in a raster of vertically oriented line elements. In addition to the uniquely oriented target, a second singleton was presented that was also different in orientation from the non-targets (i.e., tilted to the left). The results showed that when target and distractor were equally salient, both elements were selected equally often when saccadic latencies were short, but eventually, as time between display onset and saccade latency increased, the target was selected more often than the distractor. In order to vary stimulus saliency, either the target was given a unique color or the distractor was given a unique color. Note that because the target was ultimately defined by orientation, color was task-irrelevant. Nevertheless, the results showed that color applied to the target resulted in more correct saccades to the target, whereas color applied to the irrelevant distractor resulted in more incorrect saccades to the distractor (i.e., more 'capture' by the distractor). Importantly, the relative saliency of the elements affected performance only when the eye movements were initiated within 250 ms after display onset. After this time, the ability to select the correct target was not in any way influenced by the saliency of the elements (see also, van Zoest et al., 2004, 2012). Thus, evidence suggests that saccadic target selection is affected by the relative saliency of target and distractor specifically when processing of the display is limited in time.

Saccadic RT similarly was also shown to modulate deviations of saccadic trajectories (Godijn & Theeuwes, 2004; van Zoest et al., 2012; Walker et al., 2006). For example, results of van Zoest et al. (2012) showed that when stimulus-salience was varied in terms of orientation contrast, saccades deviated more towards the more salient distractor than to the non-salient distractor; moreover, the difference in deviation as a function of distractor saliency was again observed only when saccades were initiated shortly after display presentation (van Zoest et al., 2012).

Looking into the time-course of manual motor representations, the literature reveals a comparably important role for time in reaching; however, the time-course in these studies is typically studied independently of relative stimulus-salience. For example, Cisek and Kalaska (2005) showed that the motor system (i.e., the dorsal premotor area) first represents two competing target locations for selective reaching and only later the selection between them. Thus, the areas involved in the planning and execution of reaching movements do not necessarily reflect the final behavioral choice, but are linked to the dynamics of decision-making. Therefore, the trajectory of reaching movements may directly reflect competition between target and distractor representations. Song and Nakayama (2009) proposed that competition between choices is revealed in the early reach movement trajectories, thereby tracing the evolution of internal processing. In particular, reaches are initially directed to distracting stimuli (see also, Tipper, Howard, & Houghton, 2000; Welsh & Elliott, 2004) resulting in reach trajectories that deviate toward the distractor. As the conflict between the target and distractor is resolved, reaches home in on the correct goal. However, specifically how stimulus-salience influence this time-course in manual reaching is yet unknown.

### 1.3. The present study

The aim of the present study was to investigate the time-course of the effects of saliency on reach trajectories and reach target selection. The present study is based on the same saliency manipulation as van Zoest and Donk (2005). Based on previous work on saccadic performance, we hypothesize that the influence of relevant and irrelevant stimulus-salience will be limited to short-latency reaching responses. We predict that relative to the condition where target and distractor are equally salient, incidental target salience will benefit short-latency reaching responses, whereas incidental distractor salience will disrupt short-latency reaching responses. It is furthermore predicted that movements triggered later in time should not reveal any influence of incidental stimulus-salience such that performance is expected to be alike across all three conditions.

In order to be able to specifically look at short-latency responses and increase the potential impact of stimulus-salience (see also, Hunt, von Mühlenen, & Kingstone, 2007) we reduced the allowable time to complete the manual movement (time limit) from Experiment 1 (1200 ms), to Experiment 2 (740 ms) to Experiment 3 (500 ms). In Experiment 4, we measured saccadic eye movements using the exact same parameters as in Experiments 1–3 to compare the time-course of manual reaching with the time-course of saccadic selection.