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Trading off stimulus salience for identity: A cueing approach to disentangle visual selection strategies

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ABSTRACT

Recent studies show that time plays a primary role in determining whether visual selection is influenced by stimulus salience or guided by observers' intentions. Accordingly, when a response is made seems critically important in defining the outcome of selection. The present study investigates whether observers are able to control the timing of selection and regulate the trade-off between stimulus- and goal-driven influences. One experiment was conducted in which participants were asked to make a saccade to the target, a tilted bar embedded in a matrix of vertical lines. An additional distractor, more or less salient than the target, was presented concurrently with the search display. To manipulate when in time the response was given we cued participants before each trial to be either fast or accurate. Participants received periodic feedback regarding performance speed and accuracy. The results showed participants were able to control the timing of selection: the distribution of responses was relatively fast or slow depending on the cue. Performance in the fast-cue condition appeared to be primarily driven by stimulus salience, while in the accurate-cue condition saccades were guided by the search template. Examining the distribution of responses that temporally overlapped between the two cue conditions revealed a main effect of cue. This suggests the cue had an additional benefit to performance independent of the effect of salience. These findings show that although early selection may be constrained by stimulus salience, observers are flexible in guiding the 'when' signal and consequently establishing a trade-off between saliency and identity.

1. Introduction

The amount of visual information available in real world scenes goes far beyond the computational capacities of our visual system (Tsotsos, 1989, 1990). Everyday life, however, points out the innate ability of selecting from the visual stream subsets of information that are behaviorally relevant, filtering out those that are unnecessary. Information gating and distribution of attentional resources are therefore fundamental in allowing visually guided behavior. Theories and models of visual search generally assume that two major attentional mechanisms are at the basis of visual and oculomotor selection processes (Connor, Egeth, & Yantis, 2004; Corbetta & Shulman, 2002; Shipp, 2004). Bottom-up mechanisms are considered to control selection when visual search is stimulus driven (SD); that is, when the winner of selection corresponds to the more salient element present in the visual field. Visual saliency here refers to the physical, bottom-up distinctiveness of an element, and is a relative property that is contextually dependant (Itti & Koch, 2001). Top-down processes, instead, grant attention to those elements that match the observer's target settings and lead to goal driven (GD) selection behaviors. In the past, some researchers have argued that SD processes dominate visual selection (Nothdurft, 2002; Theeuwes, 1992, 2004), resulting in an attentional control predominantly driven by saliency. On the other hand, other researchers have claimed that it is GD processes which control visual selection (Bacon & Egeth, 1994; Chen & Zelinsky, 2006; Folk, Remington, & Johnston, 1992). However, while selection may sometimes be more stimulus driven than goal driven or vice versa, most researchers agree that SD and GD factors interact to ultimately control the allocation of attentional selection (Connor, Egeth, & Yantis, 2004; Duncan & Humphreys, 1989; Serences et al., 2005; Treisman & Sato, 1990).

Moreover, recent findings (van Zoest & Donk, 2006; van Zoest, Donk, & Theeuwes, 2004) have accumulated evidence for the view that SD and GD strategies influence the processing of the same visual stimuli via different time windows. The design adopted in

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these studies was based on the additional-singleton paradigm (Theeuwes, 1991). In this task, participants perform a visual search and execute a fast saccade toward a unique target presented amongst a number of identical non-targets. A singleton distractor that differs from the target in the same dimension (i.e., orientation) is presented concurrently with the search display. This distractor can be more or less salient than the target. When saccadic eye movements are measured in this type of task, the typical pattern of results shows that early oculomotor responses are frequently directed toward the most salient element in the screen (i.e., singleton target or distractor) while late saccades are more driven by the correct identification of the target. This suggests that both SD and GD control occur, but in different time windows. Further support for this view can be found in studies on attention and eye movements (Hunt, von Muhlenen, & Kingstone, 2007; van Zoest, Donk, & Theeuwes, 2004).

The entwined relationship between effects of stimulus salience and time course of responses seems critical for the understanding of the relative contribution of SD and GD processes in visual selection. However, it remains unclear as to what factors determine whether observers respond fast or slow on any particular trial, resulting in the respective adoption of either SD- or GD-dominant strategies to produce the task-demanding behavioral output. While potentially random fluctuations in cognitive control state may contribute (e.g., Esterman et al., 2013; Leber, 2010), another factor that may determine response speed is individual differences in response biases. For instance, more conservative participants may be relatively slower to respond, thereby increasing the accumulation of visual evidence to allow for better discrimination of the target. More liberal participants may instead respond faster, resulting in saccades that would tend to land on the most salient element in a display. Moreover, the balance between conservative and liberal response strategies can also occur within an individual over the course of an experiment. Observers, on the basis of performance and feedback while accomplishing a visual task, can exert on-line adaptive changes in their speed of selectivity to maximize performance. This means that the accumulation of sensory evidence will vary along a continuum and lead to different outcomes in terms of accuracy. Eventually each participant will develop a balance between speed and accuracy in order to achieve the task. With the present study, we aim to investigate whether observers are able to control the timing of saccadic selection and, if so, whether this then regulates the trade-off between stimulus-driven and goal-driven influences.

The general idea of the speed-accuracy trade-off (SAT) has been studied in the field of cognitive science for a long time (Pew, 1969; Wickelgreen, 1976) and lately has been reconsidered and investigated in neuroimaging studies (Bogacz et al., 2010; Forstmann et al., 2010) and in monkey physiological studies (Heitz & Schall, 2012). Even though the models underpinning these studies diverge on the individual dynamics of information gathering, they share the idea that sensory evidence accumulates over time from a baseline level until a certain threshold (Ivanoff, Branning, & Marois, 2008). Moreover, stimulus strength has been demonstrated to directly affect the functions underlying such dynamics, leading to different outcomes in terms of time and accuracy (Palmer, Huk, & Shadlen, 2005).

However, psychophysiological tasks in SAT studies consider fast responses to range from ~300 to ~500 ms (Forstmann et al., 2008; van Veen, Krug, & Carter, 2008). In this regard, the general idea of SAT does not easily translate to the trade-off found between stimulus- and goal-driven controls in studies of oculomotor visual selection. Oculomotor responses that occur before ~300 ms are not necessarily less accurate. For example, when the target is the most salient element on the screen in a visual search task (van Zoest, Donk, & Theeuwes, 2004) early saccades driven by the high stimulus saliency can reach performance level of ~80% accuracy (van Zoest & Donk, 2006). In fact, accuracy in target selection decreases over response time instead of increasing as described in the typical accumulator models of SAT (Donk & van Zoest, 2008). Accumulator models of SAT are able to explain performance only when the salient element is presented as irrelevant distractor; in this case performance steadily increases with time.

As already outlined, performance and efficiency in visual tasks that rely on saccadic responses depend mostly on the interaction between stimulus saliency and the selection strategies that observers adopt. However, the degree to which differing selection strategies can be voluntarily adopted by observers is still an open question. Moreover is not clear yet if observers are able to control and regulate the trade-off between speed and accuracy in oculomotor selection tasks that involve differing levels of saliency.

Finding that observers are able to control the extent to which selection is saliency-driven or guided by goal-directed intentions is in line with the general idea that overall performance depends on observer strategies. Recent evidence for early strategic influences has been reported in manual reaction time (Müller et al., 2009; Thomson, Willoughby, & Milliken, 2014), eyetracking (Geyer, Müller, & Krummenacher, 2008; Moher et al., 2011) and electrophysiology (Töllner, Müller, & Zehetleitner, 2012) studies. For example, Moher et al. (2011) explored suppression of salient capture by manipulating the probability of distractor presence in the search array. They found that the degree of distractor interference decreased as distractor appearance probability increased, arguing that this was due to participants having greater incentive to apply suppression. Taken together, these studies suggest that distractor interference is under volitional control, supporting the idea that top-down expectancies can alter observer's strategies at early stages of perceptual attentional selection. However, findings from these studies are rarely ever directly related to the time-course of performance.

The current study aimed to examine whether observers could utilize cues to produce different SAT strategies in oculomotor selection. Recent SAT studies have shown that the use of explicit cues emphasizing speed or accuracy can induce specific behavioral strategies both in humans (van Veen, Krug, & Carter, 2008) and non-human primates (Heitz & Schall, 2012). van Veen, Krug, and Carter (2008) demonstrated that, in line with cued instructions provided before a block of trials, participants could alter their manual response performance in a Simon task to emphasize speed at the cost of accuracy and vice versa. Heitz and Schall (2012) manipulated central fixation color to instruct primates to make either a fast, neutral or accurate saccadic response in a visual search task. Their findings show that primates can also proficiently adjust their behavior in line with cue instructions. The main question then is how the potential flexibility regarding when to make an eye movement may interact with the dynamic influence of stimulus salience in visual selection.

2. Experiment

In order to investigate whether observers are able to modulate and control visual selection strategies efficiently, trial-wise instructions emphasizing task speed or accuracy were given. Specifically, participants were cued to either make a fast or an accurate saccade to the target. The target was a uniquely oriented line element surrounded by a series of homogeneously oriented non-targets. Together with the target and non-targets an additional distractor of unique orientation was presented. The distractor was always tilted to the opposite direction of the target and could vary in orientation to be more or less salient than the target (as determined by orientation relative to the non-targets).