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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.

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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).

If it is the case that observers are able to control the timing of visual selection, we expect to find a difference in saccadic reaction times (SRTs) between the two cue conditions. More specifically, in the <u>fast</u> condition observers should be able to make rapid saccades and consequently be more influenced by the relative salience of the unique elements displayed. On the other hand, in the <u>accurate</u> condition we expect participants to slow down and so be more likely to avoid fast salient capture, allowing them to direct a greater proportion of saccades to the target. The cue may furthermore influence the time-course of selection. In this case we expect that the entire distribution of selection responses will shift to a later moment in time in the accurate cue condition compared to the fast cue condition. The main question then, is how this shift in time will affect the time-course of accuracy performance. It may be the case that an overall slower time-course will not affect the underlying trade-off processing between stimulus- and goal-driven controls. That is, the cue will affect SRTs, but the underlying function will be same in both cue conditions: the only difference between the cues being the result of observers accessing the function at different moments in time. Alternatively, it may be that the cue has an additional effect on the time-course function. Independent of the delay in the distribution of responses, the cue may qualitatively change the information sensitivity that guides the responses. This may increase performance in the accurate-cue condition relative to the fast-cue condition, above and beyond what is to be expected on the basis of time alone.

3. Methods

3.1. Participants

Twenty young adults (11 females, average age 23.5 years, range 20–28 years) participated as paid volunteers. All subjects reported having normal or corrected-to-normal vision. Two participants were excluded from the analyses due to a high percentage of errors (>30%, error specification in the results section). The study was conducted in accordance with ethical standards codified by the World Medical Association in the Declaration of Helsinki and written informed consent was obtained from participants before the experiment.

3.2. Apparatus

A tower mount PC, (Dell Precision T1600) based on Intel Xeon (3.10 GHz) technology with 8.00 GB of RAM coupled with a high performance 19″ monitor (ViewSonic E96f+SB, display area 360 × 270 mm, refresh rate 100 Hz) were used for stimulus presentation. The experimental design was realized with Psychtoolbox 3 (Psychophysics Toolbox Version 3; Brainard, 1997; Pelli, 1997) in combination with MATLAB R2010b. Eye movements were recorded with the Eyelink® 1000 (SR research). All participants were sitting at a distance of approximately 600 mm in front of the monitor with the head supported by a chinrest. The experiment took place in a sound-attenuated lab with suffused light.

3.3. Stimuli

Participants were asked to perform a visual search task (Fig. 1) in which they had to make a saccade to a target. For half of the participants, the target consisted of a right-tilted bar (i.e., a line segment tilted 45° to the right of a vertical axis), while the other half looked for a left-tilted bar (i.e., a line segment tilted 45° to the left). The target was embedded within a raster of non-targets (i.e., vertically oriented line segments). Together with the target and the raster of singleton non-targets, an additional distractor was presented. The distractor was always tilted to the opposite direction of the target and could vary in orientation to be more (67.5°) or less (22.5°) salient than the target, henceforth referred to as MS and LS conditions, respectively. All elements (1 target, 1 distractor, and 287 non-targets) were arranged in a 17 × 17 matrix display with a raster width of 290 × 210 mm (27.2° × 19.9° of visual angle). The target and unique distractor could appear at four different locations set on the corners of an imaginary square such that, embedded within the matrix of non-targets, targets and distractors were always presented at equal distance from fixation (7.6° of visual angle) and separated by an angular distance of 90°.
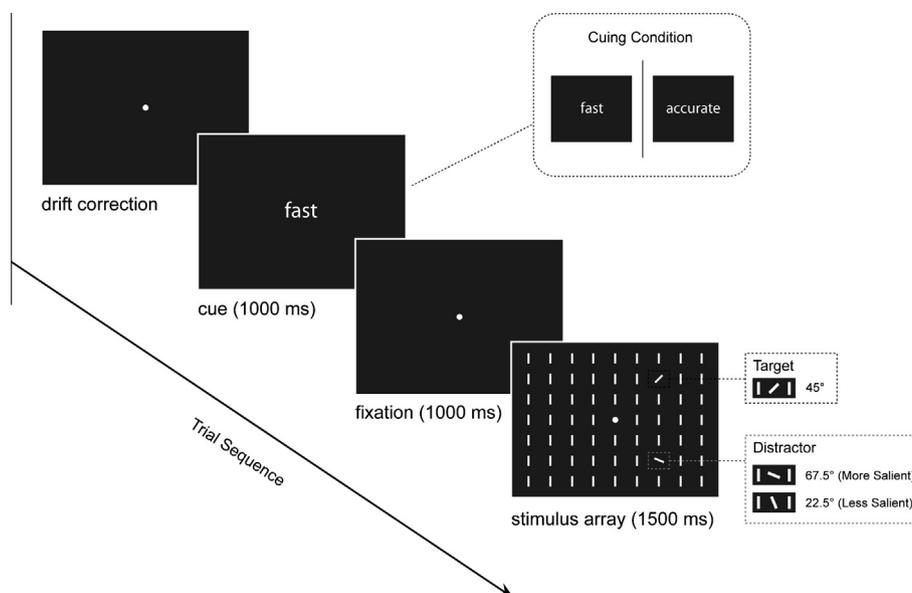
Fig. 1. Trial sequence. Participants executed a saccade to the uniquely oriented target element, depicted here as the 45° tilted segment to the right relative to vertical non-target elements. Together with the target and the raster of non-targets an additional distractor of unique orientation was presented. 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. Before the stimulus array, a display with the cue ("fast" or "accurate") was shown, indicating whether participants should be as fast or as accurate as possible in their responses. Note, stimuli not drawn to scale.

All line elements had an approximate height of 0.65° and width of 0.12° of visual angle. All elements were white and superimposed on a black background.

3.4. Design and procedure

Each trial started with a drift correction whereby participants pressed the space bar while fixating a central point. A display with a central cue ("fast" or "accurate") then appeared for 1000 ms, indicating whether participants should aim to be as fast or as accurate as possible in their response. After the cue, a display with a central fixation point was presented for 1000 ms followed by the stimulus array. The stimulus array was presented for 1500 ms. Participants were instructed to keep fixation until the appearance of the stimulus.

To make sure that the task was fully understood by the participants, oral and written instructions were given and a practice session of 32 trials conducted before the beginning of the experiment. Visual feedback on SRTs and accuracy was given to participants every 32 trials to reinforce the manipulation and to keep participants motivated throughout the experiment. Participants were instructed to be faster if the SRT mean was below 300 ms and to be more accurate if accuracy was less than 70%. A factorial design was used; cue (fast vs. accurate), target positions (4), distractor orientation (LS vs. MS) and distractor positions (2, constrained by target position) were equally counterbalanced and presented in random order. The experiment consisted of 576 trials divided into three blocks of 192 trials and lasted approximately 50 min. The eye tracker was recalibrated after each block.

4. Results

4.1. Error and data validation criteria

Saccades were defined on the basis of minimum eye-movement velocity and acceleration thresholds (30°/s and 8000°/s^2, respectively). SRT was defined as the time between the onset of the stimuli and the moment in which a saccade of at least 3° of visual angle was made from the fixation point. If the first saccade landed within a distance of 4° of visual angle from target or distractor the trial was considered valid for analyses. Trials were excluded if the initial saccade went neither to the target nor to distractor (trials rejected = 6.61%, mean SRT = 325 ms), started from more than 3° of visual angle from central fixation at the onset of the search display (trials rejected = 3.12%), initiated within 80 ms of the onset of the stimuli display (trials rejected = 0.65%), or if the SRT was larger than 2.5 standard deviations from individual participant means (trials rejected = 0.23%). These specifications led to the rejection of 10.61% of trials from the 18 participants that were included in the primary analyses.

4.2. SRTs and proportions to target

A two-by-two repeated measures ANOVA design was used to test the effects of the within-subject factors (cue: fast or accurate and distractor orientation: LS or MS) on the dependent variables (proportion to target and SRTs). Fig. 2 displays the overall mean proportion of saccades made to the target[1] and the average SRT as a function of cue and distractor orientation.

The results of the ANOVA revealed a significant main effect of the cue on proportion to target, $F(1, 17) = 61.71$, MSE = .011, $p < .001$, partial $\eta^2 = .78$. Participants were more precise in the accurate cue

condition ($M = .80$) compared to the fast cue condition ($M = .60$). A significant main effect was found for distractor orientation $F(1, 17) = 21.02$, MSE = .010, $p < .001$, partial $\eta^2 = .55$; saccades were directed more toward the target in the LS distractor condition ($M = .76$) when compared with the MS distractor condition ($M = .65$). A significant two-way interaction was found between cue and distractor orientation $F(1, 17) = 34. 21$, MSE = .004, $p < .001$, partial $\eta^2 = .67$. In the fast cue condition the orientation manipulation led to a large behavioral difference in proportion to target between the MS ($M = .51$) and LS ($M = .71$) distractor conditions. In contrast, for the accurate cue condition the difference in performance between the LS ($M = .79$) and MS ($M = .81$) distractor orientations tested with Bonferroni post hoc analyses did not show any significant difference.

The ANOVA conducted on SRTs revealed a significant main effect of cue, $F(1, 17) = 59.38$, MSE = 8461, $p < .001$, partial $\eta^2 = .78$. SRTs were shorter in the fast cue condition ($M = 280$ ms) than in the accurate cue condition ($M = 447$ ms). However, the average SRT in the MS distractor condition ($M = 367$ ms) did not significantly differ from the LS condition ($M = 361$ ms), $F(1, 17) < 2.46$.

4.3. Time-course analyses

4.3.1. Proportion to the target

To explore the relative contribution of the cue in stimulus- and goal-driven control in visual search as a function of time, mean SRTs and proportions to target were computed separately for each type of cue, distractor orientation, and for each quartile of the initial SRT distributions. Fig. 3 shows the mean proportions of correct saccades across participants as a function of quartile time bin separately for cue type and distractor orientations. A within-subject three-way repeated measures ANOVA was conducted on the proportion of correct saccades, with cue (fast, accurate), distractor orientation (LS, MS) and quartiles (1–4) as factors. All main effects (cue, distractor orientation, and quartiles) were significant, together with the three two-way interactions (cue × distractor orientation, cue × quartiles, and distractor orientation × quartiles; all $F_s(1, 17)$ and $(3, 51) > 8.93$, $p_s < .001$). Moreover, as observable in Fig. 3 and crucial for the current analyses, these effects were qualified by a significant three-way interaction (cue × distractor orientation × quartiles), $F(3, 51) = 6.41$, MSE = .008, $p < .001$, partial $\eta^2 = .27$.

To test for significant differences between distractor orientations in each quartile, post hoc analyses using Bonferroni-corrected criterion were conducted for the time-course of the accurate and fast cue condition. In the fast cue condition, distractor orientation mostly modulated the responses. In the first quartile, the saccadic behavior conveyed by proportion to target between the two distractor conditions showed a significant difference (M_s MS = .36 vs. LS = .81, $p < .001$). The second and third quartiles indicated decreasing, but still significant, differences in proportion to target between distractor conditions (2nd quartile: M_s MS = .42 vs. LS = .70; 3rd quartile: M_s MS = .54 vs. LS = .63, $p_s < .001$). This difference was not significant by the fourth quartile (M_s MS = .67 vs. LS = .65, $p > .05$).

The accurate cue condition, characterized by slower responses, shows initially the same (albeit minor) significant difference in proportion to target between distractor conditions for the first quartile (M_s MS = .57 vs. LS = .75, $p < .05$). In the second quartile no significant difference was found in performance between distractor orientations (M_s MS = .75 vs. LS = .75, $p > .05$). Intriguingly, the third and fourth quartiles appear to be characterized by an opposite tendency: participants were better able to discriminate the target when in presence of the MS distractor (3rd quartile $M = .85$; 4th quartile $M = .92$) than compared to when the LS dis-

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[1] The proportion to target is computed by dividing the number of saccades landed on target by the total number of saccades that went to either the target or distractor.
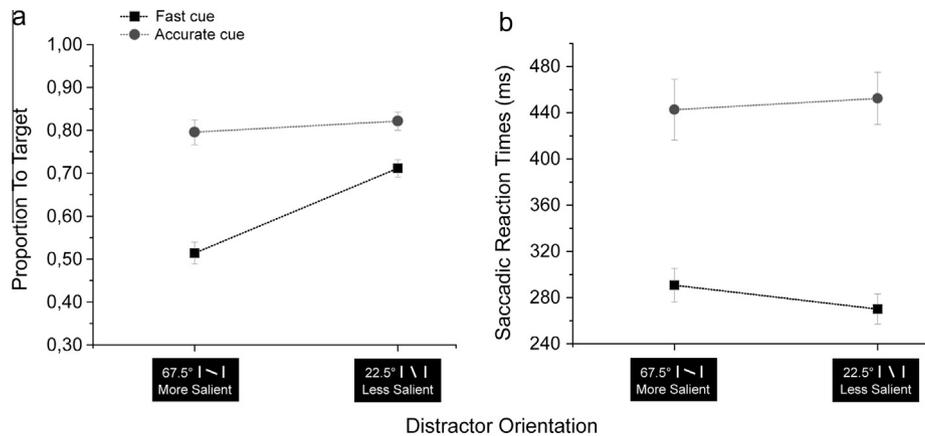
Fig. 2. Main effect of the cue on the mean proportion to target (a) and SRTs (b) as a function of distractor saliency manipulation. Error bars reflect standard errors of the mean.
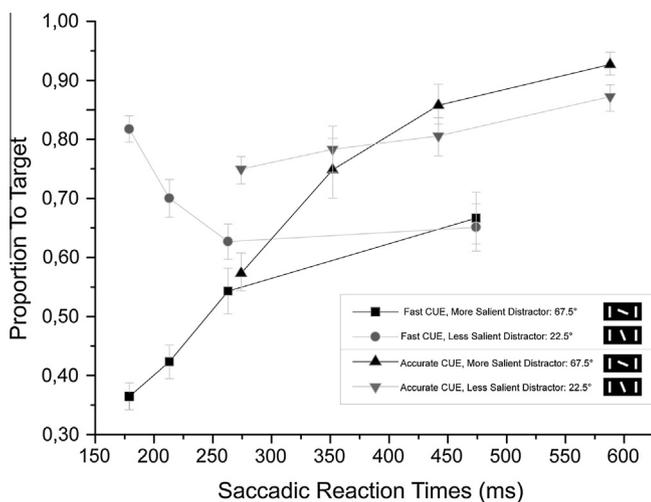

Fig. 3. Proportion of eye movements correctly directed toward the target as a function of time. Saccade latencies were divided according to cue type (fast/accurate). Fast and accurate SRT distributions were further plotted separately for each distractor condition (MS/LS) and vincentized in 4 time bins. Error bars reflect standard errors of the mean.

tractor was present (3rd quartile $M = .80$; 4th quartile $M = .87$). However, these differences were not reliable ($p_s > .05$).

4.3.2. Saccade latency

A within-subject three-way repeated measures ANOVA was conducted on SRTs with cue (fast, accurate), distractor orientation (LS, MS) and quartiles (1–4) as main factors. Of the main effects (cue, distractor orientation, quartiles), cue: $F(1,17) = 49.10$, MSE $= 36,221$, $p < .001$, partial $\eta^2 = .74$, and quartiles: $F(3,51) = 229.24$, MSE $= 3751$, $p < .001$, $\eta^2 = .93$, were significant, while distractor orientation effect was not ($F(1,17) < 2.90$).

The significant interaction of cue × quartiles ($F(3,51) = 18.27$, MSE $= 2686$, $p < .001$, partial $\eta^2 = .51$) shows that the distribution of latencies in the fast cue condition was narrower compared to the accurate cue condition (from 179 ms to 372 ms following fast cues vs. 274 ms to 588 ms following accurate cues). The significant interaction between distractor orientation and quartiles was significant ($F(3,51) = 5.28$, MSE $= 101$, $p < .05$, partial $\eta^2 = .24$), with post hoc comparisons indicating a significant difference only for the fourth quartile (M MS $= 474$ vs. M LS $= 486$, $p < .001$).

The interaction between cue and distractor orientation ($F(1,17) < 1.00$) was not significant, showing that there were no

differences in SRT to the target in the LS or in the MS distractor as a function of the cue manipulation. Moreover, time did not modulate this pattern as evidenced from the absence of a significant three-way interaction (cue × distractor orientation × quartiles, $F(3,51) < 1.00$).

An additional analysis assessed whether the large influence of salience was a common feature of rapid responding across (vs. solely within) individual SRT distributions. A correlation was performed on the relationship between an individual's 'Saliency Effect' (proportion to target in the LS – MS distractor orientation condition) and mean SRTs for each participant in the two cue conditions. If the time-course of performance also affects selection generally between participants, it was predicted that observers that were fast to respond should have a larger Saliency Effect than observers who were on average slow to respond. In contrast, if the time-course was primarily restricted to within-in subject variability, this pattern of results should not be present. The analyses revealed a negative trend between the size of the Saliency Effect and latency of SRTs in the fast-cue condition ($r(18) = -0.44$, $p = .065$) and a significant negative correlation in the accurate-cue condition ($r(18) = -0.53$, $p < .05$). These results provide partial support for the hypothesis that generally, the faster a participant is, the more likely they will be influenced by salience.

4.4. Interim discussion

These results demonstrate that participants were able to utilize the cue to modulate their oculomotor responses in time and accuracy domains. Specifically, in line with the cue, the fast cue responses were faster and less accurate overall than the accurate cue responses, which were slower and more accurate. Observers were able to guide the 'when' signal (see also, Findlay & Walker, 1999).

As predicted by the time-course of selection, performance in the fast-cue condition was primarily driven by stimulus salience. Early responses in time, as expressed in the time-course analyses, were mainly directed to the most salient element, which was the target (45°) in presence of the less salient distractor (22.5°). In contrast, when the distractor was more salient (67.5°) than the target (45°), oculomotor responses landed most frequently on the distractor. This effect slowly disappeared over response time: in the last quartile, despite a general decrease of accuracy when the target was the most salient element there were no differences in proportion to target as a function of distractor saliency.

The accurate-cue condition, on the other hand, was characterized by overall slower oculomotor RTs and an increase in performance accuracy. Visual search was guided to a greater extent by

observers' intentions even though relatively fast responses were still affected by the distractor saliency manipulation. These results demonstrate the cue effectiveness as a top-down modulator used by participants to regulate the speed-accuracy trade-off in performing the visual search task.

However, we also observed a vast difference in the SRT distributions between the two cue conditions. The responses in the accurate-cue condition showed overall slower latencies and a wider distribution while the fast-cue condition was characterized by relatively quicker oculomotor responses and a narrower distribution. Such observations were supported by a chi-square test comparing the proportion of responses in each quadrant between the two distributions ($\chi^2(3, N = 4634) = 1375$, $p < .001$). Despite these differences, there was an overlap in SRT between responses of fast and accurate distributions. Thus, the question that remains is to what extent does the cue affect performance, independently of time-course differences? That is, if we match for SRT across both cue conditions, is performance qualitatively different between cue conditions? Or instead, is performance solely based on the time-course of selection? If the cue has a distinct contribution to performance, we would expect to find an overall difference in accuracy between the two cue conditions when matched for SRT. Alternatively, if the cue no longer affects performance, the outcome of selection would be completely determined by when in time the saccade is executed.

4.5. Further analyses

4.5.1. Methods

For each participant, we first extracted the distribution of saccadic responses that temporally overlapped across both fast- and accurate-cue conditions. Because SRTs in the fast-cue condition occurred earlier in time than in the accurate-cue condition, this was accomplished by taking the fastest (i.e., lower limit) of the accurate cue responses and the slowest (i.e., upper limit) of the fast cue responses. This initial trimming created two response distributions within the same time range. Because the frequency distributions of trials within the selected time window were not equivalent across both cue conditions, we equalized the frequencies in each cue condition using a histogram function. Histograms (each with 10 bins) were created separately for the fast-cue and accurate-cue overlap distributions and the frequencies in each bin were then matched across cue condition, such that both had equal number of trials in each of the 10 bins. Participants were only included if they had at least 140 trials across the 10 bins; this led to the exclusion of one more participant from the further analyses. A two-tailed paired-samples t-test comparing extracted SRT means for fast- vs. accurate-cue conditions was not significant ($t(16) = 1.40$, $p = .18$), allowing for the subsequent comparison of performance accuracy between the two cue conditions. The new SRTs, matched for time and trial-frequency, were then used to calculate the new vincentized time-course of performance (three bins, see Fig. 4).

4.5.2. Results: Proportion to target

The effect of cue on performance for the SRT intersecting distributions was tested with a three-way repeated measure ANOVA (factors: cue × distractor orientation × tertiles) as shown in Fig. 4. The analyses revealed a significant main effect of cue ($F(1, 16) = 14.93$, MSE = .017, $p < .002$, partial $\eta^2 = .48$): overall performance accuracy benefited from the accurate cue ($M = 0.71$) compared to the fast cue ($M = 0.63$). The significant main effect of distractor orientation ($F(1, 16) = 9.37$, MSE = .044, $p < .008$, partial $\eta^2 = .37$) followed the direction of the previous analyses: despite an equivalent time-course the MS distractor (67.5°) elicited generally worse performance ($M = 0.61$) than the LS distractor (22.5°; $M = 0.71$). In the significant two-way interaction between cue × distractor orientation ($F(1, 16) = 6.43$, MSE = .008, $p < .05$,
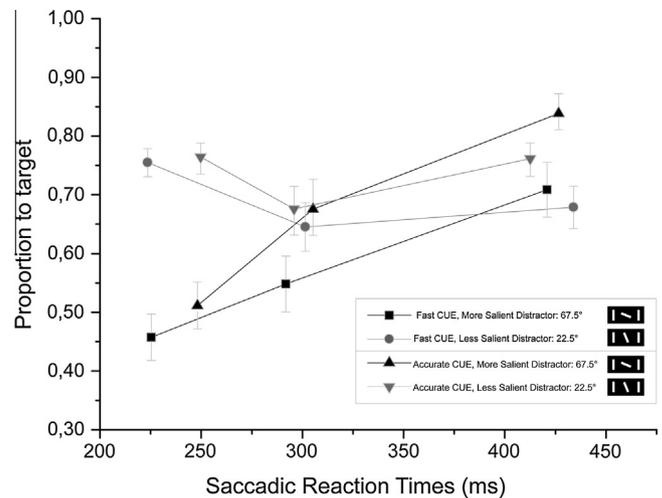

Fig. 4. New vincentized time-course of performance (3 bins) computed on the basis of the oculomotor responses that overlap in time. Error bars reflect standard errors of the mean.

partial $\eta^2 = .29$) a greater difference was observed between distractor conditions in the fast-cue (M_s MS = 0.57 vs. LS = 0.69) compared to the accurate-cue condition (M_s MS = 0.67 vs. LS = 0.73). As expected, the increase in proportion to target as a function of tertiles was also significant ($F(2, 32) = 15.36$, MSE = .020, $p < .001$, partial $\eta^2 = .49$). There was a significant two-way interaction between distractor orientation and tertiles ($F(2, 32) = 26.52$, MSE = .018, $p < .001$, partial $\eta^2 = .62$). Neither the cue × tertiles interaction ($F(2, 32) < 2.20$) or the three-way interaction between cue, distractor orientation, and tertiles ($F(2, 32) < 0.20$) were significant.

5. General discussion

Our results show that independent of the cue, short-latency saccades were driven by stimulus salience and long latency responses were primarily goal directed. Importantly, for the aims of the present study, we found evidence that observers are able to control the timing of saccadic visual selection by following the trial-wise instructions. Selection in the fast cue condition was characterized by rapid saccades while the accurate cue condition was characterized by overall slower oculomotor responses. Looking at the overall performance as a function of time-course, the trade-off in the fast cue primarily showed stimulus-driven selection based on saliency early in time; evidence for goal-driven control was only found in the final time bin, where stimulus salience no longer influenced selection. Instead, goal-driven processes predominantly guided the trade-off in the accurate cue condition; stimulus salience only influenced performance for the fastest responses. It appeared that observers' timing of responses based on the cue influenced this trade-off between stimulus- and goal-driven strategies. In sum, guided by the cue, observers were able to elicit faster or slower eye movements thereby consequently exerting adaptive changes in their visual search strategies, making selection relatively more stimulus- or goal-driven.

The present results suggest that the ability to elicit either a fast or slow response is flexible: participants are able to adopt a 'fast' or 'accurate' strategy before each trial, depending on the task instructions. This has a consequent effect on whether search processes are primarily stimulus- or goal-driven. Specifically in the fast-cue condition participants may have been prompted into a cognitive state that allowed rapid attentional deployment characterized by fast and salient captures; goal-driven control was severely limited in this case. On the other hand, in the accurate-cue condition, partic-

ipants appeared to refrain from fast responding and so were able to avoid salient capture; observers were more accurate in making correct eye movements to the designated target. These results indicate that while performing the task, participants were able to optimize their internal states to guide behavior, that is, observers were able to enter a state of cognitive control in which performance was optimized to accomplish the task in the given situation (Miller, 2000). Our results thus illustrate an important role of an observer's preparedness in solving a task. Interestingly, a negative association between the magnitude of the Saliency Effect and individual SRTs suggests that the trade-off between stimulus- and goal-driven selection as a function of response time is not solely explained by intra-subject variability. Observers who were faster overall to respond showed a larger effect of saliency than those who were generally slower.

Critically, however, when SRTs were matched between cue conditions, while there were no longer any differences in the trade-off between stimulus-driven and goal-driven selection, overall performance accuracy in the accurate-cue condition was better than in the fast-cue condition. This finding suggests that the cue may have qualitatively changed the sensitivity related to the accrual of information that guided the visual selection process. The performance enhancement in the accurate-cue condition relative to the fast-cue condition suggests that mechanisms of selection can alter sensitivity prior to saccadic execution depending on a given strategy.

The present findings are in line with a SAT study on monkey physiology (Heitz & Schall, 2012) where primates were instructed to perform a visual search task where they had to saccade to a specific target (L or T shapes) presented concurrently with distractors (L or T shapes). Before each trial, monkeys were cued to either make a fast, neutral, or accurate saccade. Monkeys were able to produce saccades in line with the cue and moreover, Heitz and Schall found that activity for visual salience neurons started to differ 300 ms before the onset of the stimuli for fast and accurate cues. Specifically, the neuron discharge rate was significantly greater and increased more rapidly over time in the fast, than in the accurate, cue condition. These results suggest that fast saccades are rapidly engaged from pools of visually responsive neurons that encode stimulus salience. Visually responsive neurons in the frontal eye field (FEF), superior colliculus (SC), and posterior parietal cortex (PPC) can modulate their firing rate according to top-down guidance instructions (i.e., cue and stimuli's physical properties).

The overall performance benefit that we observed in the accurate cue condition when SRTs were matched between cue conditions, suggest that mechanisms of selection can be more sensitive prior to saccadic execution. Pre-stimulus effects of preparation have also been reported for feature-specific instructions in a recent fMRI study from Serences and Boynton (2007) and in a monkey physiology study (Hayden & Gallant, 2005). The results of these studies suggest that feature-based attention can be enhanced before the stimulus presentation by increasing sensitivity to certain features (i.e., orientation, color) facilitating the perception of behaviorally pertinent stimuli. Although the above studies do not directly refer to saccadic selection, these mechanisms seem to affect the oculomotor system as well. A recent study (Weaver, Paoletti, & van Zoest, 2014) reported an increase of performance in very early saccades when a feature-informative cue (color) regarding the target was given to participants rather than a neutral cue. However, the results of the present study differ in that the enhancement concerned a general feature-independent improvement in performance. As far as we are aware, this study is the first to show that this type of aspecific information can affect saccadic efficiency in humans. However, unlike the feature-specific preparation benefit apparent from the fastest saccadic responses under 200 ms (Weaver, Paoletti, & van Zoest, 2014), the general benefit in the present study seemed to take more time to be established. The benefit from the accurate cue was only observable after 250 ms, the time it typically takes for goal-driven strategies in orientation search to be expressed (van Zoest, Donk, & Theeuwes, 2004). Still, the present data are limited to this respect because of the absence of data before 250 ms in the accurate-cue condition. Based on the present data, it cannot be determined whether the general enhancement following the cue can also be established for the fastest oculomotor responses.

However, while not necessarily related to the speed of saccadic selection, Moher et al. (2011) showed that advanced aspecific information concerning the likelihood of distractor appearance affects oculomotor performance. In their study, the proportion of distractor to no-distractor trials was manipulated while participants performed an additional-singleton task. Their results showed that the degree of distractor interference varied as a function of distractor appearance probability: oculomotor capture was reduced when the probability of distractor appearance was increased. This finding was taken to suggest that distractor interference is under volitional control, in that observers could voluntarily and flexibly adopt top-down attentional control settings to ignore rapidly salient distractors. However, one caveat to consider when probabilities of conditions are varied is that intertrial repetitions co-vary with probability. Specifically, intertrial priming is more likely to occur when the probability of distractor presence is increased. This then may have affected the ability to ignore the distractor and reduce oculomotor capture (see also Theeuwes, 2013). Moreover, it is unclear how this type of cueing is related to the time-course of performance. For example, in relation to the potential intertrial priming, it may be the case that observers were relatively slow to respond when the probability of distractor appearance was high. This SRT decrease could have increased the relative goal-driven control compared to a situation where observers were relatively fast to respond when distractor probability was low.

The time window between the cue presentation and the stimulus appearance, also known as pre-stimulus phase, has recently gained importance among the scientific community and has been showed to impact stimuli perception not only in psychophysiological experiments (Hanslmayr et al., 2007), but also in the specific context of visual search studies (Mazaheri et al., 2011). Interestingly, a recent study by Leber (2010) revealed that different degrees of distraction could be predicted by specific pre-trial activity in the middle frontal gyrus (MFG) as recorded by fMRI. Noninvasive physiology techniques with better temporal resolution than fMRI such as electroencephalography (EEG) and magnetoencephalography (MEG) may be able to provide more insight on the mechanisms that underlie changes in sensitivity before stimulus presentation. Irrespective of any cue, it may be that brain states themselves could also impact the strategy that participants adopt on any particular trial. Future investigation on visual selection strategies based on brain-state dependent stimulation (Jensen et al., 2011; Silvanto, Muggleton, & Walsh, 2008) may open new ways to assess how brain signatures proper of specifics and different attentional states affect saccadic control in humans.

The present results differ in an important way from traditional SAT studies that typically account for a linear relation between accuracy and speed with which a task is solved. Based purely on stimulus saliency, performance need not be inaccurate when responses are speeded. Specifically, performance was initially very accurate when the target was salient and the distractor not salient (accuracy >80%). As control increased, performance decreased as a function of saccade latency. It is presently poorly understood how neurons that encode stimulus-salience are related to this negative slope found in the fast-cue condition (see also, Donk & van Zoest, 2008; van Zoest & Donk, 2008). A possible explanation is that independent of stimulus identity, observers suppress salience activity.

While this strategy is counterintuitive when the target is the most salient element, it eventually leads to selection that is in accordance with the required task. Based on this explanation, stimulus-driven processes would impact oculomotor responses only when the responses are made before the active inhibitory processes take place (Godijn & Theeuwes, 2002; McSorley, Haggard, & Walker, 2006). Alternatively, it may be the case that independent of goal-driven strategies, saliency related activity rapidly decays over time in a passive fashion (Cheal & Lyon, 1991; Donk & van Zoest, 2008; Nakayama & Mackeben, 1989; Nothdurft, 2002; Yantis & Jonides, 1990). As a consequence, later selection would become less and less influenced by the early stimulus-driven activity elicited by highly salient targets.

In order to distinguish between these accounts using data from the present study, we conducted an additional analysis to test whether active suppression of the target occurred when appearing at a former distractor location. If there is an active suppression of saliency, then we would expect that the location of suppressed distractor saliency would inhibit selection of a target presented at the same location on a subsequent trial. Alternatively, if saliency rapidly (i.e., within a trial) and passively fades, then we would not expect previous location of a salient distractor to influence performance on a subsequent trial. Participants were observed to be significantly slower and less accurate to select a target when it was presented in the same location as a distractor on a previous trial.[2] This finding is consistent with that of a recent study showing that singleton distractors elicit location-specific inhibition (Gaspar & McDonald, 2014). Although these results do not rule out the account that stimulus influence rapidly and passively fades out, the analysis provides evidence supporting an active suppression of distractor location from one trial to the next.

The present study revealed that individual observers are relatively flexible regarding the extent to when a response is triggered. This 'when' signal in turn, determined the degree to which participants were more or less driven by stimulus salience or identity. Thus, when investigating whether visual selection is primarily stimulus or goal driven, the present work demonstrates the critical importance of taking into account the trade-off between the influence of stimulus salience and target identity over time.

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[2] A two-way ANOVA was conducted on proportion to target and SRT, using within-participants factors of Cue and Previous Location (target at previous distractor location vs. target at previous neutral location; TD vs TN). Previous trial location only included subsequent trials of an identical cue condition and the neutral location referred to a location containing a vertically oriented non-target line. The analyses revealed a significant main effect of previous trial location for both SRT ($F_{(1,17)} = 14.79$, MSE = 569, $p < .01$, partial $\eta^2 = .47$) and accuracy ($F_{(1,17)} = 19.87$, MSE = .007, $p < .001$, partial $\eta^2 = .54$) performance. Participants were slower (M_s TD = 370 ms vs. TN = 348 ms) and less accurate (M_s TD = 0.59 vs. TN = 0.68) to select a target when it was presented in the same location as a distractor on a previous trial. There was no significant interaction between previous trial location and cue ($Fs < 3.80$).

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