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Unconscious cues bias first saccades in a free-saccade task

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ABSTRACT

Visual–spatial attention can be biased towards salient visual information without visual awareness. It is unclear, however, whether such bias can further influence free-choices such as saccades in a free viewing task. In our experiment, we presented visual cues below awareness threshold immediately before people made free saccades. Our results showed that masked cues could influence the direction and latency of the first free saccade, suggesting that salient visual information can unconsciously influence free actions.

1. Introduction

Stimuli that are not consciously perceived can affect different levels of processing (for reviews, see Kouider & Dehaene, 2007; Lin & He, 2009). For example, subliminally presented exogenous cues have been shown to automatically capture spatial attention and influence perception in behavioral (Hsieh & Colas, 2012; Hsieh, Colas, & Kanwisher, 2011; McCormick, 1997; Mulckhuyse, Talsma, & Theeuwes, 2007; Tan & Hsieh, 2013; Van der Stigchel, Mulckhuyse, & Theeuwes, 2009) and neurophysiological studies (Thompson & Schall, 2000). This effect can be explained by an early stage of processing that extracts contrasting features of visual images and integrates them into a saliency map, which guides visual–spatial attention by the order of the activation level on the map (De Vries, Hooge, Wiering, & Verstraten, 2011; Donk & Soesman, 2010; Donk & van Zoest, 2011; Itti & Koch, 2001; van Zoest & Donk, 2010; Wolfe, 1994).

However, it is still unclear how saliency maps constructed without awareness of a visual stimulus affect oculomotor programming. In this study we examined (1) whether and how unconsciously presented information biases free saccades, and (2) if such unconscious biasing of free saccades occurs, whether the effect extends to subsequent saccades.

Free saccades can be considered a specific category of oculomotor programming. Saccades are generally classified as exogenous (stimulus-driven) or endogenous (goal-driven, Theeuwes, Atchley, & Kramer, 2000). Endogenous saccades can be further divided into instructed saccades and free saccades (Nachev, Rees, Parton, Kennard, & Husain, 2005; Pesaran, Nelson, & Andersen, 2008). Instructed saccades are performed according to pre-defined goals or schemes (which can be independent of the saliency of visual stimuli) and are usually associated with varying degrees of motivation (Ipata, Gee, Goldberg, & Bisley, 2006). Free saccades are similar to instructed saccades in that oculomotor programming can be independent of stimulus saliency. However, free saccades involve self-initiated action plans, which may be dissociated from pre-defined reward schemes and might involve a greater variety of action specificities than those defined by a task (Pesaran et al., 2008). Furthermore, a typical free choice task is composed of indifferent choices (i.e., the problem of Buridan's Ass). Such

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an arrangement produces additional conflict among action plans, since no one plan is more advantageous than another. Indeed, neurophysiological and imaging studies have shown that, compared with instructed saccades, free saccades involve stronger activation in the pre-SMA (an area related to volitional control) and higher level of fronto-parietal coherence, suggesting different underlying cognitive mechanisms in the two types of saccades (Nachev et al., 2005; Pesaran et al., 2008).

Few studies have examined how saliency maps constructed without visual awareness can affect free saccades. Given previous findings that unconscious external stimulus can affect subjectively free motor choice and gaze position (Kiesel et al., 2006; Klapp & Haas, 2005; Klapp & Hinkley, 2002; Rothkirch, Stein, Sekutowicz, & Sterzer, 2012; Schlaghecken & Eimer, 2004; Schlaghecken, Klapp, & Maylor, 2009), and that brain activity can bias free high-level intentions and judgments (Colas & Hsieh, 2014; Hsieh, Colas, & Kanwisher, 2012; Soon, He, Bode, & Haynes, 2013), we hypothesized that free saccades can be influenced by unconsciously presented stimuli. Specifically, this leads to the prediction that free saccades are more likely to be biased toward cue-consistent locations, and that the effort needed for resolving the indifferent options is reduced.

In addition, it is still unknown whether visual information presented unconsciously can bias a sequence of saccades. A recent study provides direct evidence that visual stimuli briefly but consciously presented can bias a sequence of saccades (De Vries, Hooge, & Verstraten, 2014). However, it is not clear whether similar effects can be found with unconscious visual stimuli. It is possible that unconscious salience information may be too limited in terms of temporal duration and/or spatial specificity (De Vries et al., 2011; Donk & van Zoest, 2008) to facilitate complex oculomotor programming.

In the current study, we investigated whether unconsciously presented cues can bias free saccades. We presented visual cues below awareness threshold, with equal or different levels of visual saliency, immediately before participants made two free saccades. We examined (1) whether participants were more likely to saccade to unconsciously cued locations, as opposed to non-cued locations, and (2) measured saccade latency as an index of the effort needed for saccade planning. If unconscious stimuli did facilitate saccade choice, saccade latency should be reduced (compared to a baseline without unconscious cues). In addition, we examined (3) whether visual saliency information could bias more than one saccade, i.e., both free saccades landing on cued locations, and explored (4) whether the sequence of biased saccades followed the degree of cue saliency, i.e., saccading to a more salient unconscious cue first, followed by a less salient unconscious cue.

2. Method

2.1. Participants

Twenty-three healthy adult volunteers (8 males) ranged in age 18–34 (average 22.65, SE = 0.61) participated in the experiment. All reported having normal or corrected-to-normal visual acuity. All participants provided informed consent according to a protocol approved by the Duke-NUS Graduate Medical School. Participants were compensated with $10 SGD for their participation.

2.2. Apparatus

A TOBII X60 Eye Tracker was used to record eye movements. Participants were seated with their heads held steady by a chin rest throughout the experiment. The chin rest was set to 70 cm from both the presentation screen and the eye tracker. The stimuli were generated using MATLAB and Psychtoolbox-3 (Brainard, 1997), and presented on a LCD monitor with a screen resolution of 1024×768 pixels and a refresh rate of 60 Hz. The Talk2Tobii toolbox (Deligianni, Senju, Gergely, & Csibra, 2011) was used to synchronize the eye tracker with MATLAB.

2.3. Experimental task

The stimulus configuration and experimental procedures are shown in Fig. 1. A red central fixation point remained on-screen throughout the experiment. Participants pressed the spacebar at their own pace to start each trial. In each trial, a combined forward and backward mask was each presented for 250 ms. The forward and backward masks were identical and contained 25 (arranged in a 5×5 grid) white, horizontally oriented Gabors,[1] equally distributed across the screen at fixed locations (1.56° for each Gabor, and 8.91° for the whole mask).

Unconscious cues were presented for 33 ms between the two masks. A cue was a Gabor randomly presented in four possible locations of the grid, each equidistant (2.60°) from the central fixation point. The Gabors for cues were identical to the Gabors used for the masks, except that they were vertically oriented. Four categories of cue conditions were used: No-Cue, One-Cue, Two-Cue Equal (two cues of equal saliency), and Two-Cue Different (two cues of different saliency). In the No-Cue condition, a blank screen was presented. The No-Cue condition served as a control for evaluating cue detection, and provided a baseline for evaluating oculomotor programming effort in terms of saccade latency. In the One-Cue condition, a Gabor was

[1] Gabors were created using Psychtoolbox v.3.0.9 and MATLAB (phase = 180, frequency = 0.07, spatial constant = 50, aspect ratio = 1). The (Michelson) contrast of the masks was fixed at 0.79. The contrast of the cues was adjusted across trials and calibrated for each participant.