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The nature of the global effect beyond the first eye movement

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ABSTRACT

When two or more visual objects appear in close proximity, the initial oculomotor response is systematically aimed at a location in between the objects, a phenomenon named the global effect. The global effect is known to arise when saccades are initiated relatively quickly, immediately after the presentation of a display, but it has also been shown that a global effect may occur much later in time, even for eye movements beyond the first. That is, when participants are searching for a complex target among complex distractor objects, it can take several eye movements to hit the target, and these eye movements mainly land at intermediate locations. It is debatable whether these findings are caused by the same mechanisms as those involved in the more typical global effect studies, studies in which much simpler search tasks are employed. In the current two experiments, we examined whether and under which circumstances a global effect can be found for a second oculomotor response in a search display containing two simple objects. Experiment 1 showed that the global effect only occurs when the presentation of the target and distractor objects is delayed, until after the first oculomotor response is initiated. Experiment 2 demonstrated that identity information, rather than spatial information, is crucial for the occurrence of the global effect. These results suggest that the global effect is not due to a failure to dissociate between the locations of multiple objects, but a failure to determine which one is the target.

1. Introduction

1.1. The global effect

While making sense of the world around us, we frequently saccade our eyes to locations that bear relevant information. These saccadic eye movements are needed because they bring visual information to the fovea, the only region of the retina that can process information in great detail. During saccadic eye movements the visual system can hardly process anything, but fortunate for us, saccades are extremely fast and concise. Saccades therefore appear optimized in enabling detailed visual processing, but there is one phenomenon that seems at odds with this view: the 'global effect' (Coren & Hoenig, 1972; Findlay, 1982; for review, Van der Stigchel & Nijboer, 2011). When two or more visual objects appear simultaneously and in close proximity, the initial saccade is likely to end up at a location in between the objects. Even in the case of a specific and well defined target, eye movements systematically land at intermediate locations whenever presented together with a second object. To better understand this global effect, in the present study we investigated eye movements other than the very first oculomotor response.

In order to induce the global effect, objects should be presented together in a specific region (Findlay & Brown, 2006; Ottes, Vangisbergen, & Eggermont, 1985; Van der Stigchel & Nijboer, 2013; Walker et al., 1997). For instance, Walker et al. (1997) asked participants to saccade from a fixed location in the middle of the screen to a target object as soon as this target appeared. In a large proportion of the trials, the onset of the target co-occurred with the onset of a distractor, presented at a large number of different positions and distances relative to the target. When a distractor was situated in an area of 20° around the target, i.e. in polar coordinates, the presence of the distractor affected the direction and amplitude of the saccade, whereas this was not the case for distractors presented outside this area. Moreover, whereas a distractor presented outside the area of 20° slowed the saccadic responses towards the target, a distractor presented inside this area caused saccades to be initiated more quickly relative to when the target was presented alone.

Initially, the global effect has been perceived as reflecting the automatic tendency to move the eyes to the center of gravity (Coren & Hoenig, 1972). According to this account, saccades are automatically and reflexively directed towards the average location of spatially poorly resolved visual signals (see also, Ottes,

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Vangisbergen, & Eggermont, 1984). More recent explanations commonly include an additional top-down component (Godijn & Theeuwes, 2002; Marino et al., 2012; Meeter, Van der Stigchel, & Theeuwes, 2010; Trappenberg et al., 2001). For instance, Godijn and Theeuwes (2002) described a model in which visual stimuli induce peaks of activity in a 'saccade map', a map reflecting the retinotopic configuration of the visual scene. The activity levels in this map can be modulated by both stimulus- and goal-driven signals, so the direction of saccades is determined by the goals of the observer as well as the intrinsic characteristics of the stimuli. Crucially, when objects appear close together, a combined activity peak is induced, instead of separate peaks, which reflects the weighted average of the objects. In turn, this leads to saccades that are aimed at intermediate locations in between objects. According to this "weighted-average" account, the global effect results from automatic stimulus-driven mechanisms, but can also be influenced by goal-driven mechanisms.

Another characteristic of the global effect concerns the timing of the oculomotor response. Over time the strength of the global effect wears off as saccades gradually become more selective (Coeffe & Oregan, 1987; Findlay, 1982; Ottes, Vangisbergen, & Eggermont, 1985; Van der Stigchel & Theeuwes, 2005). Interestingly, this is not just the case for tasks in which observers search for a target, but also for tasks lacking a specific target description, tasks in which observers are free to move their eyes. For instance, Findlay (1982) demonstrated that when participants had to compare the stimuli presented in a current trial to those presented in a previous trial, saccadic latency negatively correlated with the strength of the global effect, i.e., the eyes tended to be directed in between the stimuli most profoundly when latencies were short. The effect was not completely abolished for the longest latencies though, but as the mean latency was well below 200 ms, responses may have been too fast for the global effect to disappear. Indeed, later studies revealed that the global effect can be prevented by delaying the oculomotor response (Coeffe & Oregan, 1987; Ottes, Vangisbergen, & Eggermont, 1985).

As these findings demonstrate that long-latency eye movements do not exhibit a global effect, at least not to a comparable extent as short-latency eye movements, they are in line with the centre-of-gravity and the weighted-average accounts. According to the centre-of-gravity account a reduced global effect results from an increase in the quality of the spatial signals with processing time: long-latency saccades are based on higher spatial resolution than low-latency saccades. Consequently, long-latency saccades can be directed towards single objects more accurately. According to a weighted-average account, the global effect emerges because top-down processes did not yet determine which object corresponds to the target. As time passes by, top-down activity may accumulate at the location of the target, leading to more target-directed saccades, and thus a less pronounced global effect.

1.2. Beyond the first eye movement

Taking these explanations, one could expect the global effect to be completely absent for eye movements beyond the first, because a substantial amount of time has passed once these eye movements are initiated. Surprisingly, however, a number of studies suggest differently (Findlay & Brown, 2006; Findlay & Kapoula, 1992; Vishwanath & Kowler, 2003; Zelinsky, 2008; Zelinsky et al., 1997).

One notable example concerns a study of Zelinsky et al. (1997). Zelinsky et al. (1997) had participants search for a real-world object among other real-world objects while eye movements were recorded. Their results showed that when it took more than one saccade to position the eyes at the correct location of the target, the intermediate eye movements were mostly aimed at locations in between the presented objects rather than at the objects themselves. These findings can be interpreted as a global effect that is more persistent, even occurring well beyond a first eye movement. The authors explain the observed global effect by assuming that the human visual system cannot process identity information in great detail if located in the periphery. Therefore, there initially emerges uncertainty as to which of multiple potential target areas is the right one. To solve this, saccades are assumed to be initially directed to intermediate locations in the scene, purposefully, such to move the fovea closer to the potential targets. From this renewed position the visual system is far better able to determine where to find the target. According to such an explanation, the global effect does not arise from inaccurate location information (Coren & Hoenig, 1972; Ottes, Vangisbergen, & Eggermont, 1984) or an inability to exert sufficient top-down control (Marino et al., 2012; Meeter, Van der Stigchel, & Theeuwes, 2010; Trappenberg et al., 2001; Van der Stigchel, Meeter, & Theeuwes, 2006), but merely because participants purposefully aim for intermediate positions to enhance the information gain in the subsequent fixation. Importantly, Zelinsky et al. used rather complex target and distractors which indeed required (para)foveal vision to be discriminated from each other. Accordingly, it might well have been the case that observers were actively aiming for intermediate locations to obtain sufficient information about potential targets.

Typically, a global effect task involves extremely simple stimuli, so it remains debatable whether the findings of Zelinsky et al. (1997), involving rather complex search objects, relate to the same mechanisms as those described in the more traditional line of global effect research. Often, participants are set to search for a letter (Coeffe & Oregan, 1987), a cross (Walker et al., 1997), or for instance a disk among diamonds (Van der Stigchel & Theeuwes, 2005). There are even studies in which participants do not even have to aim for a specific target (Findlay, 1982; Silvis & Van der Stigchel, 2014; Van der Stigchel, Heeman, & Nijboer, 2012), and yet also under these conditions, when it should not have been necessary to first resolve the precise target position, a global effect occurs. Accordingly, there is much reason to believe that the global effect is primarily stimulus-driven, at least in single-saccade paradigms. The aim of the present study is to investigate whether a (classic, more typical) global effect can be observed in a second eye movement in simple displays in which target and distractor can be easily distinguished from peripheral vision.

2. Experiment 1

2.1. Description

The first experiment was aimed to examine whether the global-effect phenomenon can be induced in a relatively simple but typical global effect task involving two rather than one eye movement. In this two-eye-movement (TEM) task, participants were asked to first move to a second fixation dot, before making an eye movement towards a target element, which appeared simultaneously and in close proximity to a distractor. In every block of trials the first movement had to be aimed in a fixed direction, away from the target. There were two conditions: (i) the no-delay condition, a condition in which the stimuli (target and distractor) were presented from the start of the trial, and (ii) the object-delay condition in which the stimuli were presented during the first eye movement.

In addition to TEM, the experiment also involved a separate session of trials in which merely a single eye movement was required. This single-eye-movement (SEM) task was equal to TEM except that participants did not move their eyes to a second fixation dot