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Effects of salience are both short- and long-lived

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ABSTRACT

A salient object can attract attention irrespective of its relevance to current goals. However, this bottom up effect tends to be short-lived (e.g. <150 ms) and it is generally assumed that top down processes such as goals or task instructions operating in later time windows override the effect of salience operating in early time windows. While the majority of studies on visual search and scene viewing comply with the assumptions of top down and bottom up processes operating in different time windows and that the former overrides the latter, we point to some possible anomalies in decision research. To explore these anomalies and thereby test the two key assumptions, we manipulate the salience and valence of one information cue in a decision task. Our analyses reveal that in decision tasks top down and bottom up processes do not operate in different time windows as predicted, nor does the former process necessarily override the latter. Instead, we find that the maximum effect of salience on the likelihood of making a saccade to the target cue is delayed until about 20 saccades after stimulus onset and that the effects of salience and valence are additive rather than multiplicative. Further, we find that in the positive and neutral valence conditions, salience continues to exert pressure on saccadic latency, i.e. the interval between saccades to the target with high salience targets being fixated faster than low salience targets. Our findings challenge the assumption that top down and bottom up processes operate in different time windows and the assumption that top down processes necessarily override bottom up processes.

Most contemporary theories of visual attention agree that attention is influenced by top down and bottom up processes, such as the relevance of an object to the current goal and the salience of an object relative to its surroundings (Corbetta & Shulman, 2002). However, what contemporary theories do not agree about is the extent to which bottom up control influences attention. At one extreme, some authors have argued that in everyday tasks bottom up control, exemplified by for instance salience, plays little or no role in the control of eye movements (Tatler, Hayhoe, Land, & Ballard, 2011). At the other extreme is a class of models predicting continuous influence of salience on eye movement control (Borji & Itti, 2013; Itti & Koch, 2001). Between the two extremes is a third view which assumes that in some way bottom up control depends on the extent of top down control. One view, for instance, assumes that bottom up control of attention is operative in a short time window immediately after the onset of a visual scene (Donk & van Zoest, 2008; Theeuwes, 2010; Van Zoest, Donk, & Theeuwes, 2004), the main idea being that top down control requires more time while bottom up features such as salience are processed faster (de Vries, Hooge, Wiering, & Verstraten, 2011). Immediately after or perhaps overlapping this early time window, top down control becomes operative and overrides bottom up control (Goschy, Koch, Müller, & Zehetleitner, 2013). We here refer to this intermediate position as the *timing account* as proposed by Van Zoest, Donk and Theeuwes (see also Foulsham & Underwood, 2007; Tatler, Baddeley, & Gilchrist, 2005; Theeuwes, 2010).

The timing account is more flexible than the two extreme views on bottom up control and perhaps may consequently account for a wide range of observations. For instance, several studies have demonstrated a fast decaying effect of salience as a function of saccadic latency, i.e. the time from stimulus onset to a saccade is made to the target, with short-latency saccades being primarily salience driven and long-latency saccades being primarily top down driven (Donk & van Zoest, 2008; Goschy et al., 2013; Van Zoest & Donk, 2006; Van Zoest et al., 2004). Although these studies suggest that the effect of salience dissipate after the first saccade, a second group of studies in which eye movements have been measured over a longer time window suggest a slower decay in the effect of salience (Foulsham & Underwood, 2007; Fuchs, Ansorge, Redies, & Leder, 2011; Helo, Pannasch, Sirri, & Raemae, 2014; Parkhurst, Law, & Niebur, 2002; Tatler et al., 2005). These studies are not necessarily at odds with the timing account seeing that the effect of salience typically wanes within the first 10–20 fixations to the scene. In the absence of top down control, presumably in free viewing or memory encoding tasks, salience may influence eye

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movements beyond the first 20 saccades (Foulsham & Underwood, 2007; Tatler et al., 2005) while tasks where top down control is presumably strong, bottom up control is completely overridden (Einhäuser, Rutishauser, & Koch, 2008).

Overall, these findings seem to fit with the timing account and the general assumption that bottom up control influences eye movements as long as no top down control is operational, e.g. early after stimulus onset or in free viewing or memory encoding tasks. However, there is a last group of studies that do not quite fit the picture. These studies have shown that salience influences eye movements in decision tasks and that these changes furthermore influence the eventual choice (Bialkova & van Trijp, 2011; Lohse, 1997; Milosavljevic, Navalpakkam, Koch, & Rangel, 2012; Navalpakkam, Kumar, Li, & Sivakumar, 2012; Orquin, Bagger, & Mueller Loose, 2013; Towal, Mormann, & Koch, 2013). The challenge for the timing account is that almost all decision theories assume that eye movements in decision-making are entirely under top down control (Orquin & Mueller Loose, 2013). While many decision theories may be wrong in their strong assumption, there is little doubt that decision tasks are heavily influenced by top down control. For instance, more than 40 studies show that decision-makers are more likely to fixate information that has a high utility or validity, i.e. information that is important to the task (Orquin & Mueller Loose, 2013). According to the timing account and the assumption that top down control cognitively overrides bottom up control, salience effects should therefore have no room in decision-making. Looking closer at these studies does in fact suggest some concessions to the timing account. Milosavljevic et al. (2012), for instance, found that salience mainly predicts fixations and choice under short exposure times (<200 ms) and when preferences are weak, i.e. presumably exerting less top down control. Orquin et al. (2013) found that over the course of multiple decision trials, the effect of individual preferences on eye movements increases while the effect of bottom up processes such as size and salience decreases. However, most of the decision studies do not employ any time constraints, nor do they analyze the temporal profile of salience; to accommodate their findings of the timing account, we would have to assume that the effect of salience is operative only in an early time window after stimulus onset. A short-lived effect of salience on the other hand seems inconsistent with the findings that salience influences choice.

A different interpretation of these studies suggests that, at least for decision tasks, top down control does not necessarily override bottom up control. If, for instance, salience is correlated with the utility or validity of information, it could potentially enhance the decision outcome by increasing attention to high-utility choice options and decreasing attention to low-utility options. In such a situation salience would effectively serve as a heuristic (Gigerenzer & Goldstein, 1996) reaching better decisions with less effort. From a cognitive process perspective, it has been suggested that top down and bottom up processes may compete in parallel so that over time the most suitable process is chosen (Nyamsuren & Taatgen, 2013). Given a correlation between salience and utility, e.g. a foraging monkey prefers ripe fruit because of its superior calorie density, but ripe fruit also has a different color than the surrounding foliage (Hiramatsu et al., 2008), these models would predict an increasing reliance on salience over time (Anderson, Laurent, & Yantis, 2011).

Considering these theories and the findings that salient cues influence both eye movements and decision outcomes, it seems that there is some reason to expect a longer lasting effect of salience in decision tasks. However, none of the previous studies allow us to verify this hypothesis and the question therefore remains: Does top down control override bottom up control in decision tasks, and, if so, in what time window? The timing account proposes that top down control should either completely override bottom up control except for the first or second saccade (fast decay) or that bottom up control may wane over the course of the first 10–20 fixations (slow decay).

Whether or not this prediction holds has implications for our understanding of top down and bottom up control and to test this assumption we conducted a study on top down and bottom up control of eye movements in decision-making. As an operationalization of top down and bottom up control, we manipulated the *valence* and *salience* of one product feature, i.e. a product label, in a consumer choice task for different food products. Salience was manipulated by changing the color and contrast of the label while valence was manipulated by providing participants with positive, negative, or neutral (control) information about the meaning of the label. As dependent variables we analyzed the likelihood of saccadic selection and the latency of saccades to the manipulated label for each position in the absolute and relative saccade order.[1] For the absolute saccade order, i.e. the ordinal saccade number for any object in the task, the timing account predicts a waning effect of salience within the first 10–20 saccades with a maximal effect of salience immediately after stimulus onset. Furthermore, given stronger top down control in the positive and negative valence conditions relative to the control condition, the timing account also predicts an attenuated or even lacking effect of salience in the positive and negative conditions. For the relative saccade order, i.e. the ordinal saccade number for saccades to the label, the timing account predicts a complete overriding of salience effects after the first saccade to the label as the participant now possesses information about the object, which will allow top down control (Henderson, Weeks, & Hollingworth, 1999).

1. Methods

1.1. Participants

A large sample consisting of 150 participants was recruited through a consumer panel provider to represent a broad sample of the Danish population. Two participants were excluded after the experiment due to insufficient data quality resulting in a total sample of 148 participants. The sample size was decided by allocating 25 participants to each cell in the experiment thereby exceeding a suggested threshold of minimum 20 observations per cell (Simmons, Nelson, & Simonsohn, 2011). The participant age range was 30–65 years ($M = 46.32$) with an approximately even distribution of male and female participants (77 women). Only participants who had normal or corrected to normal vision were included in the study. Each participant received approximately €20 for completing the experiment.

1.2. Stimuli and apparatus

The experimental stimuli consisted of eight choice sets, each with two alternatives presented on the left and the right side of the screen. The alternatives were high resolution images of existing consumer products matched on preference rank in a pilot study. The manipulated product feature, a biotechnology label, was assigned to one alternative in each choice set and the salience of the label was manipulated by controlling the contrast. Eye movements were recorded using a table-mounted eye tracker (Tobii T60 XL) with a temporal resolution of 60 Hz and a screen resolution of 1920 × 1200 pixels. The screen subtended a visual angle of 46.5° horizontally and 30.1° vertically. At the average viewing distance of 60 cm from the screen, binocular accuracy is .5° and precision .18°. Fixations were computed using the velocity based I-VT algorithm (Salvucci & Goldberg, 2000). For each choice set an area of interest (AOI) was drawn around the biotechnology label. To

[1] Readers who are more familiar with analyzing eye movements in terms of fixations may think of our dependent variables as the likelihood of fixating the label and the latency of that fixation, i.e. the time from stimulus onset until the beginning of the fixation. We prefer the terms saccadic selection and saccadic likelihood to maintain consistency with previous literature on this subject.