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Feature- and category-specific attentional control settings are differently affected by attentional engagement in contingent attentional capture

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ABSTRACT

A distractor can capture attention and impair target processing when it shares a target-defining property and matches specific attentional control settings (ACS). We studied how feature-specific ACS (fACS) and category-specific ACS (cACS) operate in a conjunction search task and how they are influenced by attentional engagement. The feature- and category-matching level and temporal lags between the distractor and target were manipulated in a rapid serial visual presentation (RSVP) task. The N2pc component and impairment of target identification, which are associated with attentional allocation at an earlier stage and response selection at a later stage, respectively, were measured as markers of attentional capture. The interaction of two ACSs was observed in behavioral data, but disappeared in N2pc data, suggesting two-stage processing of multiple ACSs during a conjunction search, including an early independent and a late integrated stage. Moreover, a reliable N2pc was observed for fACS regardless of the sufficiency of attentional engagement, whereas the N2pc for cACS was only observed with sufficient attentional engagement, but disappeared when the attentional engagement was insufficient. This suggests that cACS demands sufficient attentional engagement, while fACS does not. In conclusion, fACS and cACS can be activated independently at an earlier stage, but they are integrated at a later stage during a conjunction search task and are differently influenced by attentional engagement.

1. Introduction

Abrupt or salient stimuli can involuntarily capture attention. Although many studies have demonstrated that attentional capture involves bottom-up processing (Yantis & Jonides, 1984; Theeuwes, 1991, 1992), more researchers have found that attentional capture can also reflect top-down processing. For example, a contingent attentional capture hypothesis (Folk, Remington, & Johnston, 1992) assumes that attentional capture can be guided to stimuli that match the current target-relevant property. To be specific, only an abrupt onset distractor can capture attention when the target is defined by onset, while only a color singleton distractor can capture attention when the target is defined by color. Moreover, an attentional control setting (ACS) is assumed to determine the target-relevant property and allocate attentional resources to the corresponding objects or locations. For instance, when participants are searching for a red target, a red-specific ACS prioritizes attention to the "red" property and inhibits the processing of "non-red" properties. Similar to the attentional template (Desimone & Duncan, 1995; Olivers, Peters, Houtkamp, & Roelfsema, 2011), the ACS can store and process target-relevant properties for subsequent visual search and attentional selection.

The ACS can be tuned to the feature level and category level. At the feature level, many studies have confirmed attentional guidance by ACS to onset and offset (Atchley, Kramer, & Hillstrom, 2000; Kiss & Eimer, 2011), motion (Folk, Remington, & Wright, 1994), and color (Folk, Leber, & Egeth, 2002; Folk, Leber, & Egeth, 2008; Lamy, Leber, & Egeth, 2004). For example, a distractor sharing the target-defining color (e.g., red) could impair the identification of the target embedded in a rapid serial visual presentation (RSVP) stream[1], suggesting the attentional capture for this color-matching

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[1] Folk et al. (2002) referred to the impairment of target identification in a RSVP stream as a "spatial blink". A similar effect is an attentional blink (AB, Raymond et al., 1992), which refers to a temporary deficit in the identification of the second target (T2) when it follows the first target (T1) between 200 and 500 ms. The spatial blink has some similarities to AB, such as the fact that preceded target-defining stimuli can impair target identification. However, there are some differences between them. First, a spatial blink is used to investigate attentional capture for task-irrelevant distractors, involving a relatively early stage of attentional orientation (Eimer, 1996).

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distractor, and the feature-specific ACS (fACS) could operate on this attentional capture (Folk et al., 2002). At the category level, although many studies have observed a successful visual search for category-defined targets and top-down guidance by categorical representations (Wu et al., 2013; Alexander & Zelinsky, 2011; Reeder & Peelen, 2013), few researchers have focused on attentional guidance by category-specific ACS (cACS) in attentional capture (Yang & Zelinsky, 2009; Wyble, Folk, & Potter, 2013), such as when a target is defined by a specific category (e.g., fruits, weapons, or desserts) and the distractor in the target-defining category can capture attention, suggesting attentional guidance by cACS (Wyble et al., 2013).

Multiple ACSs are required for attentional guidance in natural scenes (e.g., Adamo, Pun, Pratt, & Ferber, 2008; Moore & Weissman, 2010; Irons, Folk, & Remington, 2012). For instance, a distractor matching one of the two possible target-defining colors could capture attention, suggesting the existence of two simultaneous ACSs (Moore & Weissman, 2010). However, the mechanism by which multiple ACSs operate is still unclear. One possibility is that separate ACSs can be activated simultaneously and can operate independently (Irons et al., 2012; Adamo, Wozny, Pratt, & Ferber, 2010). For example, a stimulus that matches either a pre-defined color or shape could trigger attentional capture, suggesting that color- and shape-specific ACSs can operate independently in visual search (Adamo, Wozny et al., 2010). In contrast, by assuming that ACS is held in visual working memory and only one working memory representation can be activated at a given time, many studies challenged this independent theory and claimed that multiple ACSs cannot operate simultaneously and independently in a limited visual search period (Olivers et al., 2011; Moore & Weissman, 2010; Juola, Botella, & Palacios, 2004). Instead, an integrated ACS that combines multiple dimensions is activated in a conjunction search task.

The first aim of the present study was to investigate whether fACS and cACS can be activated in a conjunction search task and the way that these two ACSs operate. A core manipulation of the present study was to define a conjunctive target by feature and category (e.g., a red letter) so that both fACS and cACS could be generated. In particular, the effects of the feature matching level (FM) and category matching level (CM) between the distractor and target could reveal the attentional guidance by fACS and cACS, respectively.

The influence of attentional engagement on attentional capture is another interesting issue. Attentional engagement has been defined as the opening of the gate for perceptual processing for identification, consolidation, and response selection (Folk, Ester, & Troemel, 2009). The attentional engagement is withheld until a target-defining stimulus occurs, and this target-defining stimulus could be a target or a target-matching distractor (i.e., the distracters that share the target-defining property). However, it is unclear whether contingent capture for target-matching distractors demands sufficient attentional engagement. Some studies have suggested that attentional capture for target-matching distractors is impaired with insufficient attentional engagement (Folk et al., 2009; Du, Yang, Yin, Zhang, & Abrams, 2013), whereas other studies have indicated that attentional capture for target-matching distractors can occur irrespective of attentional engagement (Zivony & Lamy, 2014). These previous studies usually employed an additional target-matching distractor to eliminate the attentional engagement for the critical target-matching distractor (Folk et al., 2009; Zivony & Lamy, 2014). However, it is difficult to distinguish the separate attentional capture for each target-matching distractor. In the present study, a better manipulation of reducing attentional engagement was applied by shortening the temporal lags between the distractor and target. As mentioned above, attentional engagement can be withheld by the stimuli that match the target-defining property, including the target and target-matching distractor. Therefore, the target-matching distractor would compete with the target for sufficient attentional engagement when they appear simultaneously. Accordingly, the attentional engagement for the target-matching distractor would be insufficient under the lag0 condition (appearing simultaneously with the target), but would be sufficient under the lag2 condition (2-frame lags to the target).

In sum, to investigate how fACS and cACS operate in a conjunction search task and how they are influenced by attentional engagement, we employed the RSVP task, similar to that used by Folk et al. (2002)[2], with a critical difference being that the target was defined as a combination of feature and category. The feature- or category-matching level (FM vs. CM) and the temporal lags between the target-matching distractor and target (lag0 vs. lag2) were manipulated. The impairment of target identification and the N2pc component were measured as markers of contingent capture. The N2pc component is an enhanced negativity over posterior scalp electrodes contralateral to the attended stimulus, which emerges approximately 200 ms after the onset of the visual search array. This N2pc is indicative of attentional capture for the stimuli that match the current target-defining property, and it is usually sensitive to the attention allocation at early processing stages (Eimer, 1996; Eimer & Kiss, 2008; Luck & Hillyard, 1994; but see Tan & Wyble, 2015 for a different view). In contrast, the behavioral impairment of target identification is assumed to involve response selection at a late processing stage.

2. Methods

2.1. Participants

Twenty-three undergraduate students (11 females, mean age = 23.7 years) were recruited from the Tsinghua University Forum and participated for payment. All participants had self-reported normal or corrected-to-normal visual acuity and color vision and provided informed consent.

2.2. Stimuli and procedure

Stimuli were presented on a 17 inch CRT monitor with a refresh rate of 100HZ and a resolution of 1024 × 768 pixels. The participants viewed the monitor in a dimly lit room at a distance of

In contrast, AB is used to investigate temporal attention, involving a relatively later stage of attentional selection and consolidation (Martens & Wyble, 2010). Second, relative to the dual targets in AB studies, a spatial blink employs only one target.

[2] In addition to the RSVP task used in Folk et al. (2002), two paradigms are normally used to investigate attentional capture. One is the spatial-cueing paradigm, in which a cue might occur at a valid or invalid position before a target search array (Folk et al., 1992). The spatial-cueing effect (shorter reaction times for target identification when the target was preceded by a valid cue) for a target-defining cue reflects its attentional capture. However, in the spatial-cueing paradigm, the cue and the target are presented at the same position, leading to a problem in distinguishing space-based and feature-based attentional capture. Because the present study focused on the feature-based attentional guidance by ACS and tried to avoid the confusion of space-based attention, the spatial-cueing paradigm seems to be inappropriate. Another paradigm is the additional singleton task (Theeuwes, 1991). In this task, a specifically defined target (e.g., a diamond shape) among multiple (e.g., six) simultaneously presented stimuli is required to be found. Particularly, a non-target stimulus with a salient color (e.g., a red circle contrast to other green stimuli) can capture attention and impair target identification. Because the present study would manipulate different temporal lags between the target and distractor to investigate the influence of attentional engagement, the additional singleton task in which the target and distractor are presented simultaneously also seems inappropriate.