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Invisible collinear structures impair search

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ABSTRACT

Visual attention and perceptual grouping both help us from being overloaded by the vast amount of information, and attentional search is delayed when a target overlaps with a snake-like collinear distractor (Jingling & Tseng, 2013). We assessed whether awareness of the collinear distractor is required for this modulation. We first identified that visible long (=9 elements), but not short (=3 elements) collinear distractor slowed observers' detection of an overlapping target. Then we masked part of a long distractor (=9 elements) with continuous flashing color patches (=6 elements) so that the combined dichoptic percept to observers' awareness was a short collinear distractor (=3 elements). We found that the invisible collinear parts, like visible ones, can form a continuous contour to impair search, suggesting that conscious awareness is not a pre-requisite for contour integration and its interaction with selective attention.

1. Introduction

Visual attention and perceptual grouping help prevent us from being overwhelmed by the vast amount of input that we receive at every moment. The former system selects specific information for further processing, and the latter system organizes the complex visual scene into reduced clusters according to properties, such as proximity, similarity, good continuation, common fate, and closure (Wetheimer, 1938a, 1938b). For instance, collinear integration is a grouping of smaller elements that are oriented in a collinear way (from head to tail) as one object (contour), which makes the contour easily-detectable when it is in a field of randomly-oriented elements (Field, Hayes & Hess, 1993; Field & Hayes, 2004; Freeman, Sagi & Driver, 2001; Hess, Hayes & Field, 2003).

The relationship between selective attention and collinear integration has been intensively investigated in recent years: not only does attention exert a direct effect on collinear grouping (Freeman & Driver, 2005; Freeman et al., 2001; Freeman, Sagi & Driver, 2004), collinear grouping was also reported to modulate selective attention (Conci, Müller & Elliott, 2007; Jingling & Tseng, 2013; Kimchi, Yeshurun & Cohen-Savransky, 2007; Yeshurun, Kimchi, Sha'shoua, & Carmel, 2008). Jingling and Tseng (2013) reported a puzzling impairment effect of supra-threshold collinear grouping on visual search. In their study, they showed participants a search display of 21 rows × 27 columns containing identical vertical (or horizontal) bars, except for a randomly-selected column consisting of orthogonal bars. This task-irrelevant, but outstanding, column served as a distractor, and the column bars could be grouped into a collinear (snake-like) or non-collinear (ladder-like) organization, both possessing the same high orientation contrast compared to the background. Participants judged the orientation of a target located either on the distractor column or on the other columns. Target search was *slower* when the target

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overlapped than when the target did not overlap with the collinear distractor; whereas, there was no difference for a non-collinear distractor.

The selective attentional search impairment by a task-irrelevant collinear (but non-collinear) structure is not easily explainable by any attentional models. Attentional models predict that a highly salient structure should capture attention thus any target overlapping with this structure should be more quickly detected than non-overlapping targets. Follow-up studies showed that search impairment occurs only when the collinear distractor is defined by orientation contrast, but not color or luminance contrast (Jingling, Tseng, & Zhaoping, 2013), and the same search patterns persisted despite the increased probability of overlapping targets (Tseng, Jingling, & Oh, 2012). Jingling, Tang, and Tseng (2013) used an eye movement study to show that the proportions of short-latency saccade orienting to the target, which was commonly believed to be determined by target's bottom-up salience, was significantly reduced when the target overlapped with a global collinear structure. Although these results all suggested a low-level interaction between contour integration and attention, in all of the abovementioned studies, participants were fully aware of the outstanding distractor structure, and their eyes and attention was drawn to it even though it was task-irrelevant (Jingling, Tang, et al., 2013). Here, we ask whether awareness of the collinear structure is critical for its effect on attention allocation in a visual search task.

It was long assumed that both perceptual grouping and attentional allocation require consciousness, although this view has been challenged in recent years as empirical findings started to suggest the opposite (Koch & Tsuchiya, 2007; Koch & Tsuchiya, 2012; Lamme, 2003, 2004). Blindsight and neglect patient studies found that cues or primes presented to the blind or neglect field, despite being unnoticed by patients, could orient patients' attention (Kentridge, Heywood, & Weiskrantz, 1999, 2004). At a neurophysiological level, attention and awareness are shown to be processed by distinct neutral correlates (Fernandez-Duque, Grossi, Thornton, & Neville, 2003; Koivisto & Revonsuo, 2007; Watanabe & et al., 2011; Wyart & Tallon-Baudry, 2008). This dissociation was also supported by psychophyscial observations. For example, a subliminally singleton, be it a feature singleton (Hsieh, Colas, & Kanwisher, 2011) or an ocular singleton (Zhaoping, 2008), captured attention and improved task performance at the singleton pop-out location without participants consciously reporting them. Objects defined by color, solid contour, or orientation when presented below the detection threshold (e.g., masked by the Continuous Flash Suppression (CFS) technique, Chou & Yeh, 2012; presented in a very low contrast, Zhang & Fang, 2012; or the quick orientation reversal method, Norman, Heywood, & Kentridge, 2013), led to the same-object advantage as in the literature on above-threshold object-based attention (Egly, Driver, & Rafal, 1994). Other literature, though limited, has reported that perceptual grouping can also occur without awareness. Wang, Weng, and He (2012) found that a Kanizsa triangle (formed by grouping of three Pacmen oriented in a specific way relative to each other) broke through interocular continuous flash suppression sooner than control stimuli (which were the three Pacmen oriented in a way that a Kanizsa triangle cannot induce). Lau and Cheung (2012) similarly found that a Kanizsa square survived crowding of the inducers, in which orientation discrimination of individual inducers was poor, but judgment of perceived global shape was intact with crowding. Collinear facilitation, which refers to the facilitation of detection of a central Gabor patch when it is surrounded by flankers that are oriented in a collinear way, could be induced even when the flankers were suppressed by the CFS method (Hayashi & Murakami, 2013).

In this study, we investigated whether an invisible collinear structure by perceptual grouping will impact on selective attention in a way similar to a supra-threshold collinear structure as reported in Jingling and Tseng (2013). We first identified the critical strength of contour integration for generating search impairment in Experiment 1A, then suppressed part of the distractor by the Continuous Flash Suppression paradigm (Tsuchiya & Koch, 2005) in Experiment 1B. We found significant search impairment even when the visible length of the distractor is shorter than the critical length. In Experiment 1C and 1D we reported that, after discounting the attentional effect from flashing the Mondrian pattern, the invisible contour information still exerts search impairment. In Experiment 2 we monitored observers' percept during suppression and found that, although there were great individual differences in what observers perceived, among those who experienced successful suppression ($\geqslant$70% of trials), we are able to replicate the results in Experiment 1A and 1B. In Experiment 3, we ruled out the alternative explanation of Mondrian pattern causing the search impairment. These together suggest that unseen contour information affects selective attention and impairs search performance.

2. General method

2.1. Participants

Twenty-four observers participated in Experiment 1 (A–D) in this study. One extra participant was discarded because of low average accuracy rate (<80%) across all experiments. Another twenty-four observers participated Experiment 2, two of which data were discarded due to program error. Another thirty observers participated in Experiment 3. All participants had normal or corrected-to-normal eyesight and were kept naïve about the purpose of the experiment. They signed a consent form and received course credit for participation.

2.2. Stimuli and apparatus

The stimuli were programmed by Matlab with Psychtoolbox Version 3.0.8 (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007; Pelli, 1997) against a gray background. The stimulus screen, shown by a CRT monitor (ViewSonic, 21-inch, 60 Hz),