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A dissociation between selective attention and conscious awareness in the representation of temporal order information

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ABSTRACT

Previous electrophysiological studies have shown that attentional selection processes are highly sensitive to the temporal order of task-relevant visual events. When two successively presented colour-defined target stimuli are separated by a stimulus onset asynchrony (SOA) of only 10 ms, the onset latencies of N2pc components to these stimuli (which reflect their attentional selection) precisely match their objective temporal separation. We tested whether such small onset differences are accessible to conscious awareness by instructing participants to report the category (letter or digit) of the first of two target-colour items that were separated by an SOA of 10, 20, or 30 ms. Performance was at chance level for the 10 ms SOA, demonstrating that temporal order information which is available to attentional control processes cannot be utilized for conscious temporal order judgments. These results provide new evidence that selective attention and conscious awareness are functionally separable, and support the hypothesis that attention and awareness operate at different stages of cognitive processing.

1. Introduction

Selective attention and conscious awareness are assumed to be closely linked. Phenomena such as inattentional blindness (e.g., Simons, 2000) and change blindness (e.g., Rensink, 2002) demonstrate that the appearance of salient visual stimuli or stimulus changes often goes undetected when attention is directed elsewhere. Such cases suggest that visual events need to be selectively attended in order to become consciously accessible, and that attention might act as the 'gatekeeper' for conscious awareness. These intimate links between attention and awareness have led to the suggestion that these two domains might in fact be identical (e.g., O'Regan & Noe, 2001; Posner, 1994): What we are aware of at any given moment is determined by what is currently in the focus of selective attention. However, other authors have argued that attention and awareness are functionally distinct (e.g., Koch & Tsuchiya, 2007; Lamme, 2003). Evidence for the separability of attention and awareness is provided by cases where selective attention to a particular stimulus does not give rise to conscious awareness (e.g., He, Cavanagh, & Intriligator, 1996), cases where masked invisible stimuli attract attention when their features match a currently active task set (e.g., Ansorge, Kiss, & Eimer, 2009; Scharlau & Ansorge, 2003), and cases where conscious object classification can occur in the near absence of attention (e.g., Li, VanRullen, Koch, & Perona, 2002).

An area in which links between attention and awareness have not yet been studied systematically is the processing of temporal relationships between perceptual events. It is well-known that sensory stimuli have to be separated by a minimum

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time interval in order to be consciously perceived as non-simultaneous or successive (Exner, 1875; Hirsh & Sherrick, 1961). If perceptual awareness and sensory attention are closely linked, such thresholds for the conscious perception of temporal order might directly reflect a fixed temporal resolution limit of selective attention. Sensory events are perceived as simultaneous when their objective temporal separation is too small to be detected by attentional processes. They are experienced as successive when they are separated by a time interval that exceeds the temporal threshold for their individuation by selective attention. To test this hypothesis, the temporal resolution of selective attention needs to be determined independently from observers' ability to make conscious temporal order judgments.

In a recent series of experiments (Eimer & Grubert, 2014; Grubert & Eimer, in press), we developed new experimental procedures to demonstrate that focal attention can be allocated extremely rapidly and independently to different target objects, and that the temporal resolution of attentional control processes is remarkably high. In the original study (Eimer & Grubert, 2014), two search displays with coloured alphanumerical items (digits and letters) were presented in rapid succession (see Fig. 1 for an illustration of the stimulation procedures). Both displays contained a colour-defined target and a distractor object in a different colour on opposite sides. Participants were told that there would be one target item in a particular colour (e.g., red) in both displays, and that their task was to attend to both of these targets in order to identify them and to report whether the two target items belonged to the same alphanumerical category (two letters, two digits) or not (one letter and one digit). To determine how rapidly attention could be allocated to each of the two target objects when these objects appear in rapid succession, the stimulus onset asynchrony (SOA) separating the two displays was varied between 10 ms and 100 ms. To perform the task, participants had to direct attention initially to the target object in the first display, and then allocate attention to the target in the second display. To track the time course of these two attentional processes, we measured N2pc components of the event-related potential in response to these objects. The N2pc is an enhanced negativity that typically emerges 180–200 ms after stimulus onset at posterior electrodes contralateral to the visual field of a target object in multi-stimulus visual displays, and reflects the attentional selection of candidate target objects among distractors in visual search (e.g., Eimer, 1996; Luck & Hillyard, 1994; Woodman & Luck, 1999). Because the N2pc is computed by comparing contralateral and ipsilateral ERP waveforms to targets in the left versus right visual field, no N2pc is elicited for target objects that appear on the vertical meridian (Eimer, Kiss, & Nicholas, 2011; Hickey, McDonald, & Theeuwes, 2006; Woodman & Luck, 1999). To measure the N2pc to one of the two targets independently of the N2pc to the other target, we presented one target/nontarget pair on the horizontal meridian and the other stimulus pair on the vertical meridian (Eimer & Grubert, 2014; see Fig. 1). Trials where the horizontal display preceded the vertical display (horizontal target first: H1 targets) and trials where this order was reversed (horizontal target second: H2 targets) were randomly intermixed.

When both displays were separated by a 100 ms SOA, the N2pc to H1 targets preceded the N2pc to H2 targets by almost exactly 100 ms. Critically, when the SOA between the two displays was 10 ms, the latency difference of the N2pc components to the two targets again mirrored this objective time interval precisely, as the N2pc to H2 targets emerged 10 ms later than the N2pc to H1 targets. This is illustrated in Fig. 2 (top panel, One Colour Task), which shows ERPs at lateral posterior electrodes PO7 and PO8 contralateral and ipsilateral to a horizontal target-colour object, separately for trials where this object appeared in the first display (H1) or in the second display (H2). Fig. 2 also shows the corresponding N2pc difference waveforms that were obtained by subtracting ipsilateral from contralateral ERPs. The point in time when N2pc components to H1 and H2 targets reach a pre-defined onset threshold (−1 μV) is indicated by filled circles. The observation that these two N2pc components were equal in size and overlapped in time demonstrates that focal attention can be allocated rapidly and in parallel to several target objects, with each selection process following its own independent time course. Most critically,

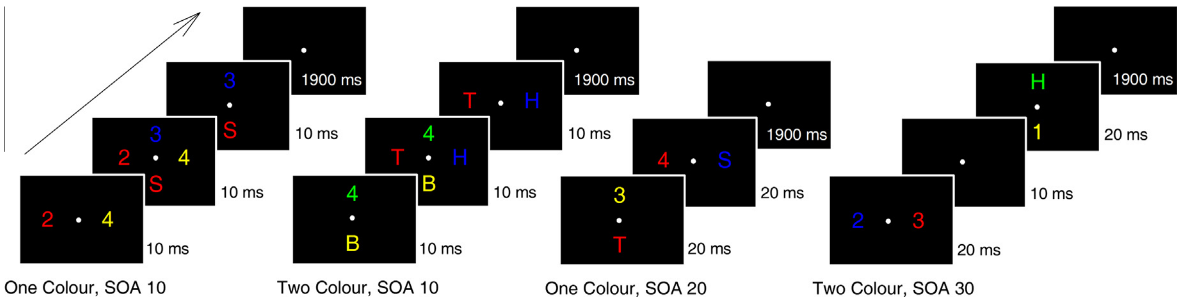

Fig. 1. Stimulus procedures. Schematic illustration of the time course of stimulus events in our previous ERP experiments (Eimer & Grubert, 2014; Grubert & Eimer, in press) and in the current behavioural study. On each trial, two displays with a colour-defined target and a nontarget-colour distractor on opposite sides were presented sequentially. One target/nontarget pair appeared on the horizontal meridian and the other on the vertical meridian. In the One Colour task, all targets had the same colour. In the Two Colour task, there were two possible target colours, and target colour always changed between the first and second display. Each display was presented for 20 ms, and the SOA between the two displays was either 10 ms, 20 ms, or 30 ms. In SOA10 trials, the second display appeared 10 ms after the onset of the first display, so that both displays were simultaneously present for 10 ms. In SOA20 trials, the onset of the second display was synchronous with the offset of the first display. In SOA30 trials, there was a 10 ms gap between the offset of the first and the onset of the second display. The examples shown in this figure include One Colour trials where both targets are red and Two Colour trials where the two targets are red and green, and all three SOA conditions. In our earlier ERP studies, participants had to judge the alphanumeric category of the two target objects (same/different). In the current study, their task was to report whether the first target-colour item on each trial was a letter or a digit. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)