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Rapid attentional selection processes operate independently and in parallel for multiple targets

Anna Grubert[a], Martin Eimer[b,*]

[a] Department of Psychology, Durham University, Queen's Campus, Stockton-on-Tees TS17 6BH, UK
[b] Department of Psychological Sciences, Birkbeck, University of London, Malet Street, London WC1E 7HX, UK

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ABSTRACT

The question whether multiple objects are selected serially or in parallel remains contentious. Previous studies employed the N2pc component as a marker of attentional selection to show that multiple selection processes can be activated concurrently. The present study demonstrates that the concurrent selection of multiple targets reflects genuinely parallel processing that is unaffected by whether or when an additional selection process is elicited simultaneously for another target. Experiment 1 showed that N2pc components triggered during the selection of a colour-defined target were not modulated by the presence versus absence of a second target that appeared in close temporal proximity. Experiment 2 revealed that the same rapid parallel selection processes were elicited regardless of whether two targets appeared simultaneously or in two successive displays. Results show that rapid attentional selection processes within the first 200 ms after stimulus onset can be triggered in parallel for multiple objects in the visual field.

1. Introduction

During the processing of visual scenes, multiple objects compete for access to visual perception and conscious awareness, and only some of these objects succeed in winning this competition by attracting attention. The question whether visual attention can be directed simultaneously to different objects or is always allocated to a single object at a time is still under dispute. Serial models of visual search (e.g., Treisman & Gelade, 1980; Wolfe, 1994, 2007) assume that objects are selected sequentially, and that attention has to be de-allocated from its previous location before it can be directed to a new visual object. In contrast, parallel models of visual attention (e.g., Desimone & Duncan, 1995) and multiple object tracking (e.g., Cavanagh & Alvarez, 2005) postulate that attention can be simultaneously allocated to several objects in a visual scene.

To assess the serial versus parallel selection of visual objects, the deployment of attention in visual scenes with multiple objects needs to be measured continuously in real time. Event-related brain potentials (ERPs) can track the time course of attentional selection processes on a millisecond-by-millisecond basis. The N2pc is a lateralised ERP component that marks the allocation of focal attention to candidate target objects in visual search (e.g., Eimer, 1996; Luck & Hillyard, 1994; Woodman & Luck, 1999). This component typically emerges 180–200 ms after stimulus onset at posterior electrodes contralateral to the visual field where a possible target object is presented, is generated in extrastriate areas of the ventral visual stream (Hopf et al., 2000), and is assumed to reflect the spatially selective enhancement of visual processing at particular retinotopic locations within these areas (see Eimer, 2014, 2015, for details). In most N2pc studies of attentional target selection, stimulus displays contain a single candidate target object among multiple task-irrelevant distractors. To employ the N2pc in investigations of the serial versus parallel nature of attentional allocation processes, this component needs to be measured in tasks where multiple task-relevant objects have to be selected concurrently. Because the N2pc is a contralateral component that is triggered when target objects appear in the left or right visual field, this component is absent for targets on the vertical meridian above or below fixation (Eimer & Grubert, 2014; Eimer, Kiss, & Nicholas, 2011; Hickey, McDonald, & Theeuwes, 2006; Hickey, Di Lollo, & McDonald, 2009; Woodman & Luck, 1999). When a target on the horizontal meridian and another target on the vertical meridian appear simultaneously or in rapid succession, the N2pc exclusively reflects the attentional selection of the horizontal target, irrespective of the concurrent attentional selection of the other vertical target. With this horizontal/vertical target presentation procedure, N2pc components can be employed to investigate serial versus parallel attentional selection processes in tasks where multiple target objects have to be selected.

* Corresponding author.
E-mail address: m.eimer@bbk.ac.uk (M. Eimer).

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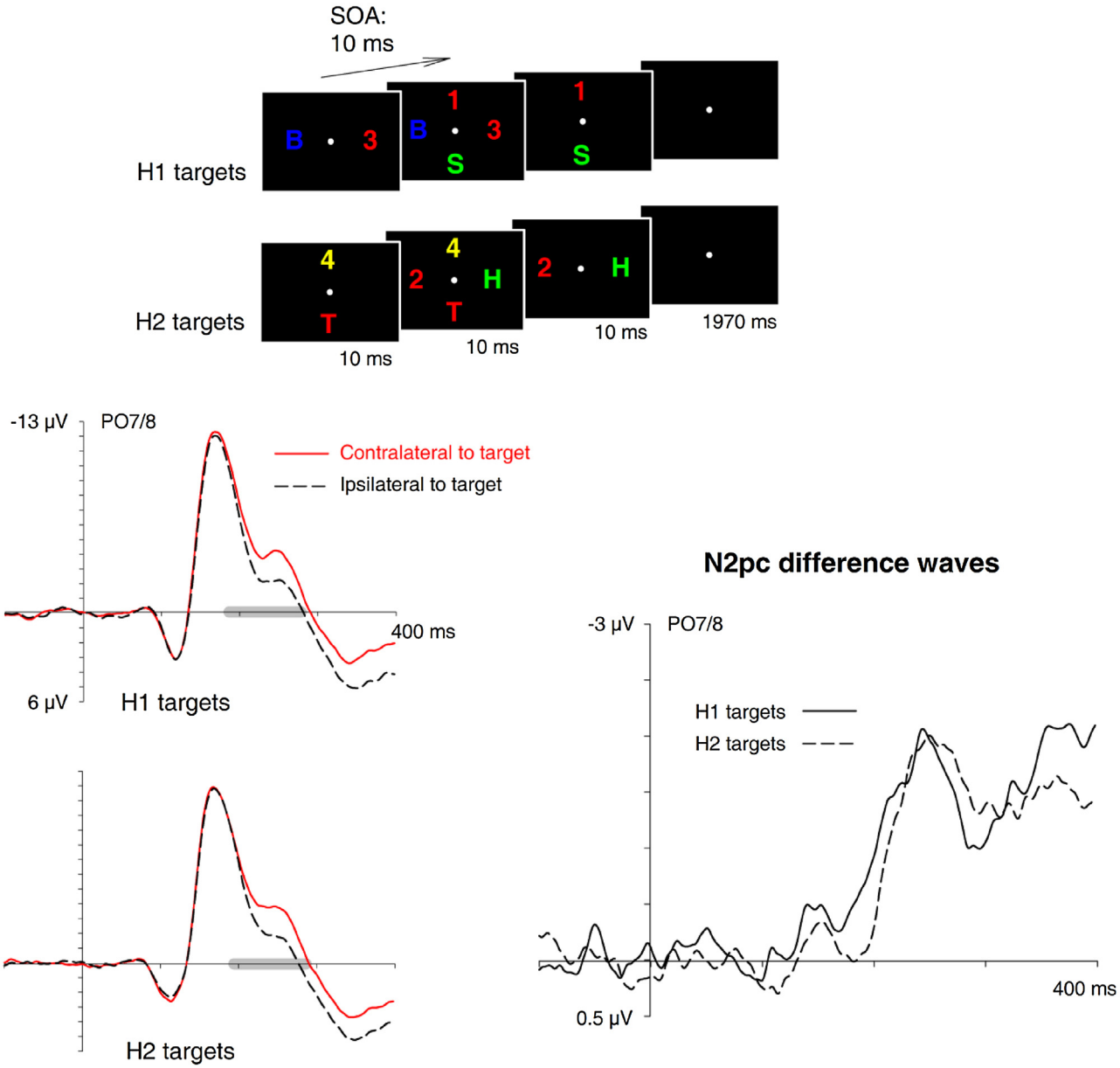

Fig. 1. Stimuli and previous N2pc results. Top panel: Schematic illustration of the time course of stimulus events in the study by Eimer and Grubert (2014). On each trial, two displays with a colour-defined target object (red in the example shown here) and a nontarget-colour distractor on opposite sides were presented sequentially for 20 ms. The SOA between the two displays was 10 ms (i.e., the two displays overlapped for 10 ms). The target/nontarget pair appeared on the horizontal meridian in one display and on the vertical meridian in the other display. Trials where the horizontal target appeared in the first display (H1 targets) or in the second display (H2 targets) were randomly intermixed. Participants had to judge the alphanumeric category of the two target objects (same/different). Bottom panel: ERP waveforms measured on trials with H1 and H2 targets at lateral posterior electrodes PO7/8 in the study by Eimer and Grubert (2014), and N2pc difference waveforms obtained by subtracting ipsilateral from contralateral ERPs. N2pc components to H1 targets preceded N2pcs to H2 targets by about 10 ms. These N2pcs overlapped in time and were equal in size. The grey bars on the x-axis indicate N2pc time windows. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

In a recent N2pc study (Eimer & Grubert, 2014), we adopted this logic to demonstrate that focal attention can be allocated concurrently and independently to two sequentially presented target-colour objects. Two stimulus displays that each contained a colour-defined target item and a distractor item in a different nontarget colour on opposite sides were presented in rapid succession. All items were letters or digits. Participants' task was to identify the two target-colour items in the two consecutive displays, and to report whether their alphanumerical category was the same (both letters, both digits) or not (one letter and one digit). The target/nontarget pair in one display always appeared on the horizontal meridian (to the left and right of fixation), and the stimulus pair in the other display was presented on the vertical meridian (above and below fixation; Fig. 1, top panel). 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. Given these stimulation parameters, N2pc components reflected the attentional selection of the horizontal target on any given trial, irrespective of a second attentional selection process for the vertical target in the other display on the same trial. When the two search displays were separated by a stimulus asynchrony (SOA) of 10 ms, N2pc components of similar size were elicited on trials with H1 versus H2 targets, and these components overlapped in time (Fig. 1, bottom panel). The N2pc to H1 targets emerged 10 ms earlier than the N2pc to