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Task relevance effects in electrophysiological brain activity: Early, but not first

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ABSTRACT

A current controversy surrounds the question whether high-level features of a stimulus such as its relevance to the current task may affect early attentional processes. According to one view abruptly appearing stimuli gain priority during an initial feedforward processing stage and therefore capture attention even if they are irrelevant to the task. Alternatively, only stimuli that share a relevant property with the target may capture attention of the observer. Here, we used high-density EEG to test whether task relevance may modulate early feedforward brain activity, or whether it only becomes effective once the physical characteristics of the stimulus have been processed. We manipulated task relevance and visual saliency of distracters presented left or right of an upcoming central target. We found that only the relevance of distracters had an effect on manual reaction times to the target. However, the analysis of electrocortical activity revealed three discrete processing stages during which pure effects of distracter saliency (~80–160 ms), followed by an interaction between saliency and relevance (~130–240 ms) and finally pure effects of relevance (~230–370 ms) were observed. Electrical sources of early saliency effects and later relevance effects were localized in the posterior parietal cortex, predominantly over the right hemisphere. These findings support the view that during the initial feedforward stage only physical (bottom-up) factors determine cortical responses to visual stimuli, while top-down effects interfere at later processing stages.

Introduction

An object may become the focus of attention due to its particular physical properties such as brightness or unique shape (bottom-up signals), or because it matches current preferences and action goals of the observer (top-down signals; Egeth and Yantis, 1997; Fecteau and Munoz, 2006; Pashler et al., 2001). A central question for the study of attention is whether a salient stimulus may capture attention automatically by overriding observer's goals or intentions (Itti and Koch, 2000; Theeuwes, 2004; Van der Stigchel et al., 2009; Yantis and Jonides, 1984), or whether attention selects stimuli based on their relevance and compatibility with current action goals (Folk et al., 1992; Gibson and Jiang, 1998; Simons, 2000). Much of recent attention research focused on the distinction between bottom-up and top-down processing, whereas less is known about when and where in the brain these complementary modes of function converge and interact.

An influential model of visual processing proposes that neural activity evoked by a stimulus moves from occipital to parietal and frontal areas in a fast, feedforward sweep (Lamme and Roelfsema, 2000). This first sweep of activity lasts approximately 100–150 ms and is followed by recurrent processing of the stimulus in the occipito-temporal cortex through feedback projections from higher-order areas. Derived from this physiological model is the proposal that attentional processing during the feedforward sweep is only affected by physical saliency of the stimulus, whereas stimulus relevance affects selection later, during the recurrent processing stage (Theeuwes, 2010; Van der Stigchel et al., 2009). An argument put forward to favour this proposal is the observation that irrelevant distracters with a unique feature capture attention (Jonides and Yantis, 1988) or gaze (Theeuwes et al., 1999; van Zoest et al., 2004) and elicit electrophysiological responses preceding activity related to processing of the relevant target (Hickey et al., 2006). In contrast, other studies using similar paradigms found that stimulus relevance is a crucial determinant of attentional capture and may affect early cortical processing of visual stimuli (Eimer and Kiss, 2008; Leblanc et al., 2008; Ptak et al., 2011; Yantis and Egeth, 1999). For instance, the capture of attention by goal-relevant features modulates event-related potentials (ERPs) approximately 180 ms after stimulus onset (Leblanc et al., 2008). However, these studies aimed to show that relevant stimulus features influence early brain activity; therefore, the saliency of stimuli was kept constant, precluding the observation of competitive or interactive effects between bottom-up and top-down processes. For this reason, their findings do not answer the question

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whether stimulus relevance effects may precede effects of saliency in early brain activity.

Here, we conducted an electrical neuroimaging study in which the saliency and relevance of the stimuli were modulated independently. Visual distracters had high or low saliency (based on luminance contrast) and could be relevant (same colour as the target) or irrelevant (different colour than the target), yet never afforded a reaction. This design allowed us to isolate temporal windows in which brain activity either reflected effects of saliency, the interaction between saliency and relevance, or pure effects of relevance.

Methods

Participants

Twenty-two elderly healthy volunteers gave written informed consent according to the Declaration of Helsinki before participating to this study. Approval was obtained from the ethical committee of the University Hospital Geneva. The data of four subjects were excluded because of EEG artefacts (excessive muscle activity, eye movements and blinks) or failure to distinguish stimulus colours during a practice run. The remaining eighteen subjects (12 females) had a mean age of 62.6 $\pm$ 7.3 years, were all right-handed, had normal vision and had no history of neurological or psychiatric illness. This study was part of a larger project that included patients with focal brain damage, and the present results are based on an in-depth analysis of the data from the age-matched healthy control sample.

Stimuli and procedure

Stimuli were presented on a 21″ CRT screen (refresh cycle 85 Hz) at 70 cm viewing distance and were upright or rotated (90, 180, or 270°) L- and T-shapes made from identical horizontal and vertical elements (size: $3 \times 3°$). Their borders were blurred with a Gaussian filter in order to eliminate sudden changes of luminance between the stimulus and the grey background. The experiment was a go/no-go task in which participants reacted to a coloured target (e.g., red) presented centrally and withheld reactions to all other stimuli presented in the centre (non-targets, e.g., green and blue). Subjects were instructed to completely ignore peripheral distracters appearing 400 ms before the target at 5° eccentricity in the left or right hemifield. Since these peripheral distracters never afforded a response the EEG time-window that was analysed (0–400 ms) was not contaminated by processes related to a decision to react or to withhold reaction. The central target and non-target stimuli were either red (RGB: 222,80,80), green (0,180,0) or blue (10,150,250) and had slightly higher luminance (25 cd/m^2) than the background (15 cd/m^2). For each subject one of these colours was randomly defined as the target colour, in a counterbalanced way. The peripheral distracters were either relevant or irrelevant and had high or low saliency. Distracter relevance was defined as the similarity with the target regarding the target-defining feature (e.g., 'redness' when the target was red) and distracter saliency as the difference in luminance compared to the background. Thus, for each of the three colour dimensions one high-saliency colour (41 cd/m^2) and one low-saliency colour (9 cd/m^2) were used (Fig. 1A). The RGB-values for the three colours were as follows: red (high saliency: 255,199,199; low saliency: 162,68,68), green (high saliency: 95,255,95; low saliency: 0,138,0) and blue (high saliency: 0,254,254; low saliency: 0,94,188).

In order to make sure that the differences in saliency effectively influenced behaviour we conducted a control experiment in which we presented the distracter stimuli in the left or right visual field (at the same positions as in the main experiment) and asked nine healthy controls (7 females, mean age: 30.5 $\pm$ 3.3) to react as quickly as possible when they perceived a specific colour (three controls for each colour). We argued that a shape with high saliency should be detected faster than a low-saliency shape; hence, that reaction times to the former should be faster than to the latter. The stimuli were presented for 300 ms and a time-window of 2000 ms was given for the answer. A repeated-measures ANOVA with factors visual field (left-LVF, right-RVF) and saliency (high, low) only revealed a significant effect of saliency ($F_{(1,8)} = 7.86$, $p < 0.05$), with shorter RTs to high-saliency (307 ms) than low-saliency stimuli (316 ms). Thus, the stimuli used as distracters in the EEG experiment were perceived differently according to their level of saliency.

Fig. 1B shows a schematic representation of the sequence of events in the EEG experiment. On every trial participants first fixated a small white cross (0.5°) shown in the middle of the screen. After 1000 ms a distracter appeared in the left or right hemifield for 300 ms, followed by 100 ms blank screen. The target display then appeared for 2000 ms. Participants were asked to press a button with their right (dominant) hand when they detected the target-colour in the centre, irrespective of shape. It was emphasized that they should never react to the peripheral distracter stimulus. There were 64 trials in each experiment block, one third of which contained a target (go trials) and the remaining a non-target (no-go trials). Within each block the four distracter conditions (high saliency/relevant; high saliency/irrelevant; low saliency/relevant and low saliency/irrelevant) varied orthogonally. Every participant completed at least twenty blocks for a total of 1280 trials.

EEG acquisition and preprocessing

Continuous EEG was acquired with a sampling rate of 512 Hz through a 128-channel Biosemi ActiveTwo system (Biosemi V.O.F, Amsterdam, Netherlands) referenced to the common mode sense/

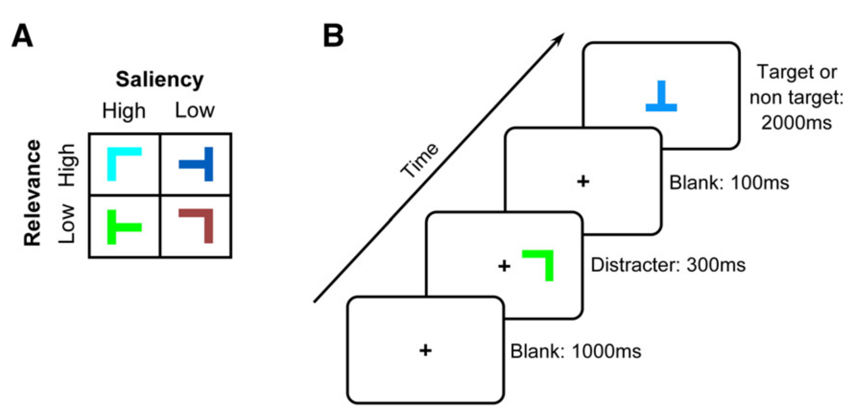

Fig. 1. A) Example stimuli used in the experiment. In this condition, the target and relevant distracters were blue while irrelevant distracters were red or green (relevance modulation). Distracters in each relevance condition either had high or low luminance contrast with the background (saliency modulation). B) Time-course of events presented in one experimental trial. The example shows a trial with an irrelevant, high-saliency distracter and a blue target. Note that in reality all stimuli were shown on a neutral grey background and that the size of the stimuli is exaggerated.