Brain Research 1673 (2017) 42–51

Contents lists available at ScienceDirect

Brain Research

journal homepage: www.elsevier.com/locate/bres

Research report

The effect of perceptual load on tactile spatial attention: Evidence from event-related potentials

Elena Gherri [a,*], Fiona Berreby [a,b]

[a] Human Cognitive Neuroscience, Psychology, University of Edinburgh, UK
[b] Université Pierre et Marie Curie, Paris, France

ARTICLE INFO

Article history:
Received 31 March 2017
Received in revised form 26 May 2017
Accepted 7 August 2017
Available online 10 August 2017

Keywords:
Tactile spatial attention
Event-related brain potential
Perceptual load
Visual information

ABSTRACT

To investigate whether tactile spatial attention is modulated by perceptual load, behavioural and electrophysiological measures were recorded during two spatial cuing tasks in which the difficulty of the target/non-target discrimination was varied (High and Low load tasks). Moreover, to study whether attentional modulations by load are sensitive to the availability of visual information, the High and Low load tasks were carried out under both illuminated and darkness conditions. ERPs to cued and uncued non-targets were compared as a function of task (High vs. Low load) and illumination condition (Light vs. Darkness). Results revealed that the locus of tactile spatial attention was determined by a complex interaction between perceptual load and illumination conditions during sensory-specific stages of processing. In the Darkness, earlier effects of attention were present in the High load than in the Low load task, while no difference between tasks emerged in the Light. By contrast, increased load was associated with stronger attention effects during later post-perceptual processing stages regardless of illumination conditions. These findings demonstrate that ERP correlates of tactile spatial attention are strongly affected by the perceptual load of the target/non-target discrimination. However, differences between illumination conditions show that the impact of load on tactile attention depends on the presence of visual information. Perceptual load is one of the many factors that contribute to determine the effects of spatial selectivity in touch.

1. Introduction

Tactile spatial attention refers to our ability to prioritize the processing of stimuli that are presented at relevant body locations. There is now convincing evidence that spatial attention improves the speed and accuracy of responses to attended tactile stimuli as compared to unattended ones in healthy humans (e.g. Sathian and Burton, 1991; Spence et al., 2000). To investigate which stages of processing are modulated by tactile attention, a number of electrophysiological studies have compared event related potentials (ERPs) elicited by tactile stimuli at cued and uncued locations. In these studies, participants attend to the cued body location to respond to infrequent target stimuli but not to frequent non-target stimuli (i.e. performing a tactile discrimination), while ignoring both target and non-targets delivered to the other uncued location. The mechanical stimulations of the fingers elicits clear sensory specific ERP components (P45, N80, P100 and N140). The early P45 and N80 components are generated in contralateral SI (e.g. Hari et al., 1984; Hamalainen et al., 1988; Zhu et al., 2007) while tactile processing is implemented by brain areas in and beyond SII from about 90 ms post-stimulus onset (corresponding to the time range of the mid latency P100 and N140 components; e.g. Allison et al., 1992; Barba et al., 2002; Frot and Mauguire, 1999). Importantly, (some of) these early components together with longer latencies ERPs are selectively modulated during tactile spatial tasks, revealing that the effects of attention can be observed during both perceptual and post-perceptual stages of somatosensory processing (for reviews, see Johansen-Berg and Lloyd, 2000; Sambo and Forster, 2011; Gomez-Ramirez et al., 2016).

However, the neural mechanisms mediating the spatial selection of stimuli in the somatosensory system remain poorly understood. In particular, the time course of the attentional modulations varies quite considerably across studies. For instance, some cuing studies reported the earliest attention effects on the mid-latency P100 or N140 components (e.g. Eimer and Forster, 2003; Forster and Eimer, 2005a; Zopf et al., 2004) while others did so at longer latencies (from the descending flank of the N140, e.g. Van Velzen

* Corresponding author at: School of Philosophy, Psychology and Language Sciences, Department of Psychology, The University of Edinburgh, 7 George Square, Edinburgh EH8 9JZ, UK.
E-mail address: elena.gherri@ed.ac.uk (E. Gherri).

http://dx.doi.org/10.1016/j.brainres.2017.08.007
0006-8993/

et al., 2002; Forster et al., 2009). One factor that might contribute to these differences is the perceptual load that determines the difficulty of the discrimination between targets and non-targets at cued locations. Differences in the discriminability of these stimuli might result in different amount of attentional resources at the cued body locations, which in turn might affect the locus of attentional selectivity and the size of the effects of attention on sensory processing.

In the visual domain, ERP studies on spatial attention demonstrated that the effect of attention on visual processing is sensitive to variations of the difficulty of the target/non-target discrimination (i.e. perceptual load) (e.g., Handy and Mangun, 2000). Larger modulations of the P1 and N1 components were observed for high load discrimination than for low load discrimination tasks (e.g., Handy and Mangun, 2000). Furthermore, the amplitude of these components increased with the amount of attentional resources voluntarily allocated to the spatial location of the ERP-eliciting stimulus (Mangun and Hillyard, 1991; Alho et al., 1992). Thus, increased perceptual demands have a systematic impact on visual processing.

No study to date has directly investigated whether analogous effects of perceptual load on attention can be observed in the tactile domain. Indirect evidence suggests that changes in the target/non-target attributes affect the efficiency of the tactile discrimination and modulate tactile spatial attention (Michie et al., 1987). In this early ERP study different intensities defined tactile targets and non-targets (weak vs. strong stimuli). Earlier effects of spatial attention and worst behavioural performance were observed when participants had to detect a weak target among strong non-targets as compared to when a strong target was presented amongst weak non-targets (effects of attention observed in the N80 and P100 time range, respectively) (Michie et al., 1987). While this study was not designed to investigate the effect of load on tactile spatial attention (the frequent non-targets analysed in the two conditions are physically different stimuli which cannot be directly compared), these observations suggest that the difficulty of the target/non-target discrimination might modulate spatial selectivity in touch.

The aim of the study reported here was to investigate the effects of perceptual load on tactile spatial attention. We used a spatial cuing task in which tactile targets and non-targets were vibrotactile stimuli defined by different frequencies. We varied systematically the difficulty of the target/non-target perceptual discrimination by decreasing or increasing the targets frequency while leaving unchanged that of non-targets. The *low load task* was characterised by a wide difference between the frequencies of target and non-target tactile stimuli (100 Hz vs. 25 Hz, respectively). In contrast, this difference was reduced in the *high load task* (40 Hz for targets and 25 Hz for non-targets). Thus, increased perceptual demands characterised the high load task as compared to the low load task. ERPs elicited by physically identical non-target tactile stimuli presented to the cued and uncued hand were compared as a function of the different load tasks (high vs. low). If the manipulation of perceptual load - operationally defined as the increased or reduced difference between targets and non-targets - affects attention by changing the locus of attentional selectivity in touch and/or by increasing the attentional resources deployed to the cued body location, we expect to observe earlier and/or stronger attentional modulations in the high load task.

An additional aim of the present study was to investigate whether the effects of perceptual load on tactile spatial attention are modulated by the presence or absence of visual information during the task. The visual system is often engaged during tactile spatial attention tasks. Even when the experimental task involves exclusively tactile stimuli, participants often receive visual cues about the tactually stimulated body part. Increasing evidence has demonstrated that the operations of tactile attention are strongly affected by this incoming visual information about the body (for a review see Sambo and Forster, 2011). Electrophysiological studies have now reported modulatory effects of vision on tactile selectivity (c.f. Eimer et al., 2003a, b; Gillmeister et al., 2010; Sambo et al., 2009). In one of these studies, attentional modulations of somatosensory processing emerged earlier when visual information was available suggesting that tactile selectivity was facilitated by visual information (specifically, the sight of the stimulated hand) (Sambo et al., 2009). Tactile spatial attention is mediated by representations of the relevant body location not only in somatotopic coordinates but also in external coordinates which are likely to be based on visual information (e.g. Eardley and Van Velzen, 2011; Eimer et al., 2001; Eimer et al., 2003a, b; Röder et al., 2008). Because vision provides highly detailed spatial information, viewing the touched body part has been suggested to facilitate the remapping of tactile stimuli in external coordinates, aiding tactile spatial selectivity (e.g. Sambo et al., 2009; Gillmeister et al., 2010).

Interestingly, behavioural studies investigating the effect of vision on tactile perception revealed that the difficulty of the perceptual task plays a relevant mediatory role in these effects. Visual information about the touched body part can improve tactile spatial acuity but these facilitatory effects of vision on touch depend on the difficulty of the task (e.g. Kennett et al., 2001; Press et al., 2004). Despite the fact that different mechanisms might be responsible for the effects of vision on tactile perception and on tactile selectivity (e.g. Sambo & Forster, 2011), these observations provide indirect evidence for interactive effects between vision and task difficulty. In the present study, we systematically manipulated not only the load of the perceptual task but also the availability of visual information. Different participants performed the same high and low load tactile attention tasks in the light or in the darkness.[1] Because both the effects of vision and perceptual load might impact the time course and the amount of attentional resources engaged during the task, we investigated whether these factors contribute separately or jointly to determine the operations of tactile spatial attention.

2. Results

2.1. Behavioural results

Performance was more accurate in the Low load than in the High load task (mean accuracy 91% vs. 77.5%, respectively; $F(1,22) = 34.5$; $p < 0.001$; $\eta_p^2 = 0.6$). Accuracy levels were comparable across illumination conditions (no main effect of illumination condition, $F(1,22) < 1$; $p = 0.4$; 96% accuracy in both illumination conditions), and similar differences between high and low load tasks were present in the light and in the darkness (no task x illumination condition, $F(1,22) < 1$; $p = 0.5$).

The analysis of response times revealed a main effect of task ($F(1, 22) = 34.4$; $p<0.001$; $\eta_p^2 = 0.6$). Vocal responses to target stimuli presented to the cued hand were significantly faster in the low load than in the high load task (608 ms vs. 682 ms, respectively). No reliable difference emerged between illumination conditions ($F(1, 22) < 1$; $p = 0.7$; 654 ms in the light and 637 ms in the darkness). Although differences between the low and high load tasks were numerically more pronounced in the darkness condition (596 vs.

[1] Because our main focus was the effect of perceptual load on tactile spatial attention, the variable illumination condition (light vs. dark) was manipulated between participants. This mixed experimental design eliminated issues related to practice/training effects (the same participants executing the high load task twice under different illumination conditions) and avoided multiple recording sessions given the substantial lengths of the experiment