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Independent effects of eye gaze and spatial attention on the processing of tactile events: Evidence from event-related potentials

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ABSTRACT

Directing one's gaze at a body part reduces detection speed and enhances the processing of tactile stimuli presented at the gazed location. Given the close links between spatial attention and the oculomotor system it is possible that these gaze- dependent modulations of touch are mediated by attentional mechanisms. To investigate this possibility, gaze direction and sustained tactile attention were orthogonally manipulated in the present study. Participants covertly attended to one hand to perform a tactile target-nontarget discrimination while they gazed at the same or opposite hand. Spatial attention resulted in enhancements of the somatosensory P100 and Nd components. In contrast, gaze resulted in modulations of the N140 component with more positive ERPs for gazed than non gazed stimuli. This dissociation in the pattern and timing of the effects of gaze and attention on somatosensory processing reveals that gaze and attention have independent effects on touch.

1. Introduction

When we feel a touch at a certain location on our body, we tend to direct our eyes to that location to look at the source of stimulation. While this orienting behaviour does not alter directly the tactile input, that is the operations of the mechanoreceptors on the stimulated skin, a number of recent studies have now demonstrated that tactile processing is modulated not only by the availability of visual information about the stimulated body part but also by the direction of the eyes.

Viewing the touched body part during a tactile task improved the discrimination of stimuli and lowered the tactile threshold (e.g. Kennett, Taylor-Clarke, & Haggard, 2001; Press, Taylor-Clarke, Kennett, & Haggard, 2004; Tipper et al., 1998, 2001). For instance, responses to tactile targets were faster when presented to the visible hand (displayed on a monitor thorough a video camera) than when they were presented to the non visible hand, suggesting that vision of the hand facilitated the discrimination of tactile stimuli (Tipper et al., 1998). In addition, psychophysical studies showed improved performance in a two-point discrimination threshold task (2ptD) when participants viewed their stimulated arm, as compared to when their arm was not visible or when a neutral object was presented in the same location (Kennett et al., 2001; Press et al., 2004). Crucially, in these experiments, visual enhancement of touch was observed despite the fact that vision of the tactually stimulated body site was completely non-informative (i.e. viewing the body did not provide any information about the tactile stimulation). Neuroimaging studies have started to unravel the neural mechanisms underlying this facilitatory effect of vision on touch. For instance, TMS and ERP evidence showed that non-informative vision can modulate early somatosensory processing, already within the primary somatosensory cortex, and that the multisensory integration of visual and tactile information is likely to be responsible for the visual enhancement of touch (e.g. Cardini, Longo, & Haggard, 2011; Cardini, Longo, Driver, & Haggard, 2012; Forster & Eimer, 2005; Fiorio & Haggard, 2005; Longo, Pernigo, & Haggard, 2011; Taylor-Clarke, Kennett, & Haggard, 2002).

Typically, when we look at a specific body site we tend to direct our eyes towards the relevant body location, to foveate the source of the relevant visual information. Thus, very often the possibility to further process visual information from a specific body site is mediated by changes in the position of the eyes (gaze direction). Intriguingly, it has been observed that also gaze direction can modulate tactile perception even when no visual information relative to the stimulated body site is available (Honoré et al., 1989; Pierson, Bradshaw, Meyer, Howard, & Bradshaw, 1991; Tipper et al., 1998). While the effect of eye gaze on touch has been less investigated, initial evidence suggests that gazing towards a specific body location facilitates the processing of tactile stimuli presented at that

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location. Behavioural studies in which participants were asked to detect or discriminate tactile stimuli presented to either hands while their gaze was directed to one of the hands, showed faster responses to stimuli presented to the hand gaze was directed, under conditions where the hands were hidden from view (Honoré et al., 1989; Pierson et al., 1991; Tipper et al., 1998).

The studies described above suggest that gazing to the tactually stimulated body part can improve tactile processing and that this effect is independent from the presence of visual information. While the available evidence indicates that vision and gaze have independent effects on touch (e.g. Forster & Eimer, 2005; Tipper et al., 1998), the functional and neural mechanisms that mediate the effect of gaze on touch remain almost entirely unknown. The proprioceptive orienting of the eyes towards the tactually stimulated body site has been suggested as one of the possible mechanisms responsible for the observed changes in tactile processing due to the manipulation of gaze direction (Tipper et al., 2001, 1998; Honoré et al., 1989). In addition, it has been proposed that the effect of gaze on touch might be mediated by spatial attention (Forster & Eimer, 2005; Pierson et al., 1991). Given that the mechanisms responsible for the allocation of attention in space are closely linked to the oculomotor system, spatial attention might be automatically directed to the gazed body location. While these two hypotheses are not mutually exclusive, none of them has been directly investigated.

Indirect support for a role of attention in the effect of gaze on touch comes from the only ERP study to date reporting modulations of somatosensory processing by gaze direction (Forster & Eimer, 2005; Exp. 3; but see also Hesse, Seiss, Bracewell, & Praamstra, 2004; for null effects of gaze on touch). In this study, participants were instructed to gaze to one hand while responding to infrequent tactile targets randomly presented to either hands (both hands were hidden under a table top). ERPs elicited by tactile stimuli presented to the gazed hand as compared to stimuli presented to the non gazed hand were characterized by enhanced N140 components followed by enhanced sustained negativities. Importantly, the pattern and time course of this effect of gaze (Forster & Eimer, 2005) are remarkably similar to those reported in previous ERP studies of covert tactile spatial attention (e.g. Eimer & Forster, 2003; Forster & Eimer, 2004; García-Larrea, Lukaszewicz, & Mauguire, 1995; Michie, Bearpark, Crawford, & Glue, 1987). When participants are explicitly instructed to covertly attend to one of their hands (and to maintain their gaze onto a 'neutral' central location equidistant to both hands), enhanced mid-latency somatosensory ERP components (P100 and/or N140), followed by enhanced Nd components (Eimer & Forster, 2003; Michie, 1984; Josiassen, Shagrass, Roemer, Ercegovac, & Straumanis, 1982) are typically elicited by attended stimuli.

The similarities between the effects of gaze (Forster & Eimer, 2005) and of spatial attention (e.g. Eimer & Forster, 2003; Forster & Eimer, 2004; García-Larrea et al., 1995; Michie et al., 1987) on somatosensory processing might suggest that manipulating gaze direction activates the same mechanisms that are responsible for the covert orienting of spatial attention in touch. However, existing data cannot provide unequivocal support for the hypothesis of a functional link between gaze and spatial attention. In all previous studies on the effect of gaze on touch (Honoré et al., 1989; Tipper et al., 1998; Forster & Eimer, 2005; Hesse et al., 2004; Pierson et al., 1991) tactile stimuli were equally likely to be presented to either hands, and participants had no incentive to focus their attention on a specific location. In other words, spatial attention was not directly manipulated. Under these experimental conditions it is possible that spatial attention was directed to the gazed location simply because it was not engaged in any other specific spatial task. Thus, current evidence does not allow to disentangle between the effects of gaze and of spatial attention on touch.

To directly investigate whether the effects of gaze and spatial attention on touch are mediated by the same mechanisms or whether these two effects are independent, both gaze direction and spatial attention were simultaneously and independently manipulated in the present ERP study. Participants were instructed to focus and maintain their covert attention on the task-relevant (attended) hand throughout a block of trials to carry out a difficult discrimination between target and non-target tactile stimuli presented to that hand, while ignoring all tactile stimuli presented to the other task-irrelevant (unattended) hand. In addition, they had to direct and maintain their gaze on the task-relevant or on the task- irrelevant hand in different blocks of trials. Somatosensory ERPs in response to tactile non-target stimuli presented to the left and right hand were compared as a function of attention (stimulus presented to the attended – task-relevant –, A+, vs. unattended – task-irrelevant – hand, A−) and gaze (stimulus presented to the hand gaze was directed, G+, vs. the opposite hand, G−). Because gaze and attention were orthogonally manipulated so that each condition of attention (A+ vs. A−) could be matched to any condition of gaze (G+ vs. G−), it was possible to investigate the electrophysiological correlates of their effects on tactile processing. If the effect of gaze and spatial attention are mediated by the same neural mechanisms, gaze-dependent and attention-dependent ERP modulations should have similar profiles and influence analogous stages of somatosensory processing. In contrast, if the effect of gaze on touch is mediated by mechanisms that are independent of spatial attention, different patterns of SEPs modulations by gaze and by spatial attention are likely to be observed. Note that if previously reported effects of gaze on touch were confounded with (and not mediated by) spatial attention, there is the possibility that no effect of gaze is observed when the direction gaze and spatial attention are orthogonally manipulated.

2. Material and methods

2.1. Participants

Nine paid volunteers (2 males) aged 21–35 (mean age of 26.9 years) participated in the experiment. Two were left handed and they all had normal or corrected- to-normal vision by self-report. All participants gave written informed consent. The study was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and was approved by the Ethics committee, Department of Psychology, City University London.

2.1.1. Stimuli and apparatus

Participants sat in a dimly lit experimental chamber. Tactile stimuli were presented using a 12 V solenoids, driving a metal rod with a blunt conical tip to the top segment of the index fingers, making contact with the fingers whenever a current was passed through the solenoid. Two tactile stimulators were used, each attached with adhesive medical tape to the left and right index finger, placed so that the metal rod made contact with the outer side of the top phalanx.

Tactile stimuli were either continuous (non-target stimuli), consisting of one rod contacting one finger for 200 ms, or contained a 6-ms gap where this contact was interrupted after a duration of 97 ms (gap stimuli). Throughout the experimental blocks, white noise (62 dB SPL) was continuously delivered from a loudspeaker centrally located in front of the participants, to mask any sounds made by tactile stimulators.

Participants were instructed to place their hands palm side down on a table with their left and right index finger positioned