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# Comparing the effects of sustained and transient spatial attention on the orienting towards and the processing of electrical nociceptive stimuli

Rob H.J. Van der Lubbe [a,c,*], Jorian H.G. Blom [a], Elian De Kleine [b], Ernst T. Bohlmeijer [b]

[a] Cognitive Psychology and Ergonomics, University of Twente, The Netherlands
[b] Psychology, Health & Technology, University of Twente, The Netherlands
[c] Cognitive Psychology, University of Finance and Management, Warszawa, Poland

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ABSTRACT

We examined whether sustained vs. transient spatial attention differentially affect the processing of electrical nociceptive stimuli. Cued nociceptive stimuli of a relevant intensity (low or high) on the left or right forearm required a foot pedal press. The cued side varied trial wise in the transient attention condition, while it remained constant during a series of trials in the sustained attention condition. The orienting phase preceding the nociceptive stimuli was examined by focusing on lateralized EEG activity. ERPs were computed to examine the influence of spatial attention on the processing of the nociceptive stimuli. Results for the orienting phase showed increased ipsilateral alpha and beta power above somatosensory areas in both the transient and the sustained attention conditions, which may reflect inhibition of ipsilateral and/or disinhibition of contralateral somatosensory areas. Cued nociceptive stimuli evoked a larger N130 than uncued stimuli, both in the transient and the sustained attention conditions. Support for increased efficiency of spatial attention in the sustained attention condition was obtained for the N180 and the P540 component. We concluded that spatial attention is more efficient in the case of sustained than in the case of transient spatial attention.



## 1. Introduction

A functional perspective on pain implies that its purpose is not to induce unpleasant feelings, but to signal the body of a potential or actual physical threat, and to induce appropriate behaviors to deal with this threat (e.g., see Legrain et al., 2011). All sensory modalities may induce warning signals that automatically trigger an attentional response (i.e., they induce exogenous orienting), however, the nociceptive system (the peripheral and central nervous system involved with signaling potential tissue damage) is specialized in this function. This view is underlined by the fate of patients suffering from congenital analgesia (see Peddareddygari et al., 2014) who often develop serious injuries that lead to a premature death. Thus, pain and attention appear to be largely intertwined (see also Eccleston and Crombez, 1999). This supposed interconnectedness between attention and pain may have further implications. For example, nociceptive stimuli may directly activate structures known to be involved with attentional orienting like the anterior cingulate cortex (ACC) and the insular cortex. This prediction has been confirmed by several neuroimaging studies (Mouraux and Iannetti, 2009; Mouraux et al., 2011; Seeley et al., 2007). It also implies that attentional manipulations like distraction or specific focused attention instructions will largely affect the cortical processing of stimuli that activate the nociceptive system (e.g., see Blom et al., 2012; Van der Lubbe et al., 2012).

Eimer and Forster (2003) compared the effects of sustained and transient spatial attention on the processing of mechanical tactile stimuli. Participants had to detect target stimuli presented at an attended location on the body. In the sustained condition, participants continuously attended to either their left or right hand during a block of trials. In the transient condition, participants had to switch attention in an unpredictable way from one hand to the other. ERPs revealed an enhanced N140 component and later negativity for attended as compared to unattended stimuli in both the sustained and the transient spatial attention conditions. However, an earlier increased contralateral negativity, around the N80, was merely observed in the case of sustained spatial attention. This finding led Eimer and Forster to suggest that sustained spatial attention can modulate processing within primary somatosensory cortex while effects of transient spatial attention concern secondary somatosensory cortex and later stages. Based on these findings, the question may be raised whether nociceptive stimuli are also affected at an earlier stage and possibly also more strongly in the case of sustained spatial attention.

In a recent study, the influence of transient spatial attention on the processing of intracutaneous electrical stimuli presented to the index

* Corresponding author at: Cognitive Psychology and Ergonomics, Faculty of Behavior, Management, and Social Science, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands.

*E-mail address:* r.h.j.vanderlubbe@utwente.nl (R.H.J. Van der Lubbe).

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fingers of the left and right hands was examined (Van der Lubbe et al., 2012). Stimulus intensity was manipulated by varying the number of pulses, which has the advantage that the same fibers are recruited (see Van der Heide et al., 2009). The early N100 and the N150 components were enhanced for attended relative to unattended stimuli. An opposite effect, an increase in amplitude for unattended stimuli, was observed for the later P260 (or P3a) component. Results of source analyses indicated that the early effects seem related to increased activity within secondary somatosensory cortex, while the enlarged P260 component for unattended stimuli may reflect increased activity in ACC. In contrast with these differential attentional effects, all aforementioned ERP components were enlarged for more intense stimuli. Examination of the estimated source activities suggested that attentional effects were rather diffuse while the effect of stimulus intensity already seemed to invoke SI. As intracutaneous electrical stimuli were employed, both nociceptive (Aδ) and tactile (Aβ) fibers were activated, therefore, it could not be concluded that observed effects concern nociception.

Interestingly, Inui et al. (2002) developed a specific type of stimulation electrode that more selectively activates nociceptive fibers (see Mouraux et al., 2010). Thus, the question may be raised whether the aforementioned transient spatial attention effects are also present when electrical stimuli more selectively activate nociceptive fibers. In line with the findings of Eimer and Forster (2003), these effects may also concern an earlier level or may simply be stronger in the case of a sustained than in the case of a transient spatial attention manipulation.

The results reported by Eimer and Forster (2003) also seem to imply that orienting itself may differ between these attentional conditions, which can be examined by focusing on attention-direction-dependent EEG activity in the orienting phase. Various attention-direction-dependent ERP components (or event-related lateralizations [ERLs]) have been observed while participants were awaiting visual, tactile, and auditory stimuli on the left or the right side (e.g., Eimer et al., 2002; Hopf and Mangun, 2000; Van der Lubbe et al., 2006). Seiss et al. (2007) examined whether the so-called anterior directing attention negativity (ADAN) and the posterior late directing attention positivity (LDAP) may be considered as multimodal (or even supramodal) components.[1] Orienting seems to be multimodal when it doesn't matter whether the to-be-attended stimulus on the left or right is auditory, visual, or tactile. Seiss et al. observed both the ADAN and the LDAP in the orienting phase when auditory cues indicated the side of auditory imperative stimuli, and concluded that these two ERL components are multimodal. However, other studies questioned the multimodal nature of the ADAN and LDAP components. For example, Eimer (2001) and Eimer et al. (2004) showed a polarity reversal in the case of a crossed arms condition, which suggests that the ADAN is related to somatosensory space rather than to external visual space. Moreover, the LDAP was not observed for blind people, which suggests that this component is related to external (visual) space (Van Velzen et al., 2006). Results of Forster et al. (2009) with tactile stimuli further question the idea that the ADAN and the LDAP are reflections of a multimodal or even supramodal orienting mechanism. A possible problem, however, is that some effects may not show up with the ERL method due to individual and especially intra-individual (trial-to-trial) fluctuations (see also Buzsáki, 2006). This variability may also depend on the type of cue that is employed as an arrow pointing to the left or right may be easier to interpret and faster processed than the pitch of a tone that signals whether you have to attend to the left or the right.

Recently, Van der Lubbe and Utzerath (2013) introduced a method that may circumvent this problem, which they denoted as lateralized power spectra (LPS). LPS can be computed after performing wavelet analyses on the raw EEG. First, the power in specific frequency bands is determined on the raw EEG for each point in time. After that an average is computed for trials in which the left or the right side had to be attended. A consequence of the computation of power is that variations in phase across trials will not lead to cancellation. Subsequently, an ipsi-contralateral power difference for symmetrical electrode pairs is determined and this difference is scaled by the sum of the power at both ipsi- and contralateral electrodes. Finally, results for left and the right attended trials are averaged (the same procedure except for this final step was already used by Thut et al., 2006). This procedure can be carried out for various frequency bands. Application of this method suggested that the LDAP may be a reflection of lateralized power changes in the theta (θ), alpha (α) and possibly even the beta (β) band. Furthermore, Van der Lubbe and Utzerath (2013) suggested that the ADAN may not always be visible due to individual differences, as application of the LPS method showed relevant lateralized activity in the θ and β bands while no ADAN was observed. Thus, earlier support for a unimodal interpretation of the ADAN and the LDAP may be due to differences in variability between the relevant conditions.

In the current paper our goal was to examine whether the impact of spatial attention on the processing of nociceptive stimuli concerns an earlier stage and/or has stronger effects when the locus of attention stays constant for a series of trials relative to when it varies from trial to trial. An answer to this question may also be relevant for training methods that try to alleviate effects of pain by employing specific attentional strategies. A comparison was made between effects of sustained and transient spatial attention conditions on lateralized EEG activity in the orienting phase, and effects of sustained and transient spatial attention on the subsequent processing of electrical nociceptive stimuli as reflected in ERPs. The nociceptive stimuli were presented on the left and right forearms. In both conditions, the to-be-attended side was indicated by a visual cue. In the transient condition, the cued side varied from trial to trial, whereas in the sustained condition, the cued side was kept constant during a series of trials. We manipulated stimulus intensity by varying the number of pulses. Only one intensity was defined as relevant for each participant. All participants were instructed to press a foot pedal when the relevant intensity occurred at the cued side (25% of the trials).

We expected to observe different lateralized ERP components in the orienting phase, which may be related to lateralized activity in specific frequency bands as determined with the LPS method. However, the LPS method may reveal new information that is not reflected in lateralized ERP components. Lateralized activity might be more pronounced in the case of sustained than in the case of transient spatial attention. We expected to observe comparable effects of spatial attention on different ERP components as in the study of Van der Lubbe et al. (2012). However, as now we employed electrical nociceptive stimuli, we expected that the different components would occur slightly later. The attentional effects on these components were predicted to concern an earlier stage in the case of sustained than in the case of transient spatial attention, in line with the earlier observations by Eimer and Forster (2003).

## 2. Methods

### 2.1. Participants

Seventeen healthy students (14 females and 3 males, age range: 20–34 years) participated in the experiment in exchange for free participation in a mindfulness training that would occur at a later moment in time. The experiment lasted about 3 h. All participants had normal or corrected-to-normal vision and reported to be free of neurological and psychiatric disorders. Sixteen participants were right-handed and one participant was left-handed, which was assessed with Annett's Handedness Inventory (Annett, 1970). Every participant received a detailed explanation of the procedure and signed a written informed consent before participating. The Medical Ethical Committee of Medisch

[1] Another earlier component has been observed, the so-called early directing attention negativity (EDAN), however, it probably reflects selection of the relevant part of the visual cue that signals the to-be-attended side (Van Velzen and Eimer, 2003), and seems therefore not very informative about the orienting phase.