

Lost in vision: ERP correlates of exogenous tactile attention when engaging in a visual task

Alexander Jones^{a,b,c,*}, Bettina Forster^c

^a Université Paris Descartes, Sorbonne Paris Cité, Paris, France

^b CNRS (Laboratoire Psychologie de la Perception, UMR 8158), Paris, France

^c City University London, London, UK

ARTICLE INFO

Article history:

Received 10 September 2012

Received in revised form

20 December 2012

Accepted 11 January 2013

Available online 20 January 2013

Keywords:

Tactile

Exogenous attention

Visual engagement

Inhibition of return

ERPs

Crossmodal

ABSTRACT

Behavioural studies have shown that when engaging in a visual task response facilitation to tactile stimuli at exogenously cued locations is diminished. Here we investigated behavioural and also neural correlates of tactile exogenous attention when participants either watched a visual stream (single task) or also detected targets in the visual stream (dual task). During the visual stream, tactile cues were presented to the left or right hand followed by tactile targets at the same or opposite hand. Behavioural results demonstrated slowed responses to tactile targets at cued locations (i.e., IOR) in the single whilst no attention effect in the dual task. Concurrently recorded EEG revealed multiple stages of tactile processing to be attenuated when engaging in a visual task: First, the amplitude of the cue-elicited somatosensory P100 component was suppressed suggesting relative early cross-modality effects in the dual task. Second, correlates of cue-induced attentional control processes showed a reduced late somatosensory negativity (LSN) in the dual compared to the single task suggesting smaller preparatory processes. Finally, early attentional selection correlates of post-target ERPs (N80) were absent in the dual task. This study demonstrated for the first time that engaging in a visual task abolished behavioural IOR in touch. ERP analyses showed that early somatosensory processing as well as specific correlates of tactile attentional orienting and target selection are diminished under visual engagement. Our findings are in line with a supramodal account of attention.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

When playing a challenging video game or watching an absorbing movie we may feel like we are lost in this visual world as events happening around us (e.g., the bell ringing) or even to ourselves (e.g., a tap on the shoulder) appear to take longer to be noticed. The ability to prioritise certain information out of the stream of sensory input constantly bombarding our senses is known as selective attention. Directing our attention consciously towards a particular spatial location or focusing on particular stimuli is generally known as voluntary or *endogenous* attention. Attention can also be driven by external stimuli in our environment which grab our attention, also known as automatic or *exogenous* attention. Much of the attention research has explored these attention mechanisms separately. However, in our everyday lives endogenous and exogenous attention processing do not typically occur in complete isolation but instead, stimulus

processing may require activating both types of mechanisms (e.g., Spalek, Falcon, & Di Lollo, 2006).

To what extent a peripheral event is processed or can influence performance in a central task has been extensively studied (e.g., Eriksen & Eriksen, 1974). Furthermore, based on these and similar findings it has been suggested that perception has limited capacity and that all stimuli are processed in an automatic fashion until the available capacity has been exhausted (e.g., Lavie, 1995; Lavie, Hirst, de Fockert, & Viding, 2004). Therefore, when engaging in a central task the extent to which peripheral, irrelevant stimuli are processed and capture our attention depends how much attentional capacity is still available. That is, when the central task is high in perceptual or attentional load and attentional capacity is fully engaged in processing task relevant information, there is little or no spare capacity to process irrelevant stimuli. On the contrary, when engaging in a task with low perceptual or attentional load, any capacity which has not been utilised in the relevant task is available to process task irrelevant stimuli. Support for this notion comes from behavioural and neuroimaging studies (see Lavie, 2004 for review). In particular neuroimaging studies have allowed insight into how irrelevant stimuli are processed during varying load. Converging evidence from fMRI

* Corresponding author at: Université Paris Descartes, 45, Rue des Saints-Peres, 75006 Paris, France. Tel.: +33 1 4286 2198.

E-mail address: alexander.jones.1@city.ac.uk (A. Jones).

and EEG studies have supported the notion that increased load in a central visual task attenuates early visual processing of task irrelevant stimuli, possibly as early as primary visual cortex (e.g., [Rauss, Pourtois, Vuilleumier, & Schwartz, 2009](#) for EEG; [Schwartz et al., 2005](#) for fMRI). However, most of the studies investigating the effects of load on processing task irrelevant stimuli have been conducted in the visual modality. Only recently, research has begun to unravel the neural basis of increased load in one modality on processing task irrelevant stimuli in another modality. For example, [Klemen, Buchel, and Rose \(2009\)](#) found that increasing auditory perceptual load decreased the BOLD response to task-irrelevant visual stimuli (see also [Klemen, Buchel, Buhler, Menz, & Rose, 2010](#)). These studies therefore suggest that effects of load are not limited to a single modality in line with a supramodal account of attention. However, what is less clear is which stages of distractor processing are modulated crossmodally.

To further understand to what extent peripheral, task irrelevant stimuli can capture attention while engaging in a task, researchers have introduced a second task (see [Santangelo & Spence, 2008](#), for a review). For example, [Santangelo, Belardinelli & Spence \(2007\)](#) have utilised a paradigm in which participants either focused their attention on a central rapid sequential visual (or auditory) presentation (RSVP), while they performed an exogenous cuing task (dual task) either in the same or a different modality. In addition, the same exogenous attention task was performed but without the RSVP (single task). That is, in all task conditions participants respond to a target at the same (cued trials) or opposite side (uncued trials) as a task-irrelevant exogenous cue. Any systematic difference between cued and uncued trials is thought to reflect the ability of the cue to attract attention. Importantly, by varying participants' engagement in the RSVP task effects of attentional/perceptual load on exogenous attention could be measured. For instance, [Santangelo and Spence \(2007\)](#) showed that varying visual attentional/perceptual load influenced processing of irrelevant tactile stimuli. More specifically, irrelevant tactile cues only had a facilitation effect on responses to tactile targets at the cued side under the low load (single task), whilst this effect was suppressed under the high load (dual task) condition. One explanation of these findings is that the exogenous cue was less able to capture attention under high load conditions; another is, that when watching the RSVP, attention is rapidly disengaged from the cue location to the visual stream. In fact, in support of the latter notion [Santangelo, Botta, Lupiáñez, and Spence \(2011\)](#) have recently demonstrated that exogenous cues can facilitate responses to targets while engaging in a RSVP task if the target is presented before a change of letter in the visual stream. However, response times to targets give only indirect measurement of the processing of the cue and it is not clear to what extent engaging in a visual task affects somatosensory processes and tactile attentional orienting and selection.

The aims of the present study were two-fold: first, to investigate crossmodal load effects on distractor processing, that is, which stages of somatosensory processing are modulated when engaging in a visual task; and second, to track the effects of increased visual load on tactile exogenous attention correlates (i.e., orienting and selection). To this end, EEG was recorded while participants performed a tactile exogenous attention task either while simultaneously watching an RSVP stream (single task/low load) or while also monitoring the RSVP stream for targets (dual task/high load).¹ Since the interval between the task irrelevant

exogenous cue and target was long we expected to find behavioural responses to show inhibition of return (IOR); that is, slower reaction times for targets appearing at a previously cued, compared to a novel location (see [Klein, 2000](#) for a review). IOR has robustly been demonstrated in exogenous tactile detection studies ([Cohen, Bolanowski, & Verrillo, 2005](#); [Lloyd, Bolanowski, Howard, & McGlone, 1999](#); [Poliakoff, Spence, McGlone, & Cody, 2002](#); [Röder, Spence, & Rösler, 2002](#); [Röder, Spence, & Rösler, 2000](#); [Jones & Forster, 2012](#)). However, to our knowledge no previous study has reported whether IOR is susceptible to attentional load manipulations in a central task. Furthermore, we aimed to analyse the ERP data in three different ways, exploring three different aspects of tactile processing and attention. First, we contrasted somatosensory ERPs elicited by the irrelevant exogenous cues during the single and dual task (*post-cue* ERP analysis). This would indicate at what stage visual engagement influences somatosensory processing. Second, we analysed later-alised ERP components during the cue-target interval to investigate the effect of visual engagement on attentional control processes (*cue-target* ERP analysis). Based on previous research, we expected to find an enhanced negativity over anterior electrode sites contralateral compared to ipsilateral to the cued side, the so called ADAN. This component has been demonstrated in response to visual (e.g., [Hopf & Mangun, 2000](#)), auditory (e.g., [Green & McDonald, 2006](#)) and tactile endogenous cues (e.g., [Forster, Sambo, & Pavone, 2009](#)) and has been argued to reflect activity within the frontoparietal attention network ([Nobre, Sebestyen, & Miniussi, 2000](#); [Praagstra, Boutsen, & Humphreys, 2005](#)). Moreover, we recently demonstrated an ADAN in an exogenous tactile task similar to the present study with enhanced contralateral negativity to the cued side ([Jones & Forster, 2012](#)). We expected this component to be followed by an enhanced lateral somatosensory negativity, the LSN, which has been suggested to reflect preparatory somatosensory activity before target presentation ([Gherri & Forster, 2012](#)). We expected this component to be suppressed when engaging in a visual task reflecting reduced availability of processing resources under dual task conditions. Third, we investigated how engaging in a visual task interacts with the more commonly reported modulations of tactile attentional selection present in *post-target* ERP analysis. Recently, we reported that exogenous tactile attention modulates somatosensory processing as early as the N80 component, followed by modulations at also the P100, N140 and Nd components ([Jones & Forster, 2012](#)). If engaging in an additional task reduces central attentional resources we would expect smaller or later tactile attentional modulations to be present. Taken together, this study provided valuable new insight into how processing of tactile stimuli is affected by varying visual engagement.

2. Methods

2.1. Participants

Seventeen paid participants (15 right-handed) took part in this study and all gave written informed consent prior to their participation. There were seven males and ten females with a mean age of 26.5 years (range: 21–35 years). One participant (right-handed female) was excluded from analysis due to excessive alpha waves.

2.2. Stimuli and apparatus

Stimuli and apparatus were identical in the single and dual tasks. Participants sat in a dimly lit, soundproofed chamber. Tactile stimuli were presented using

¹ It should be noted that visual and tactile targets were presented with equal probability. This was done to optimize the number of tactile target presentations for ERP analysis. Importantly, tactile cues were presented on every trial and although these were to be ignored when engaging in an additional visual task cue processing was modulated. Future studies may vary the level of visual

(footnote continued)

engagement by introducing different weightings for visual and tactile targets (see, for example, [Santangelo et al. \(2007\)](#)).

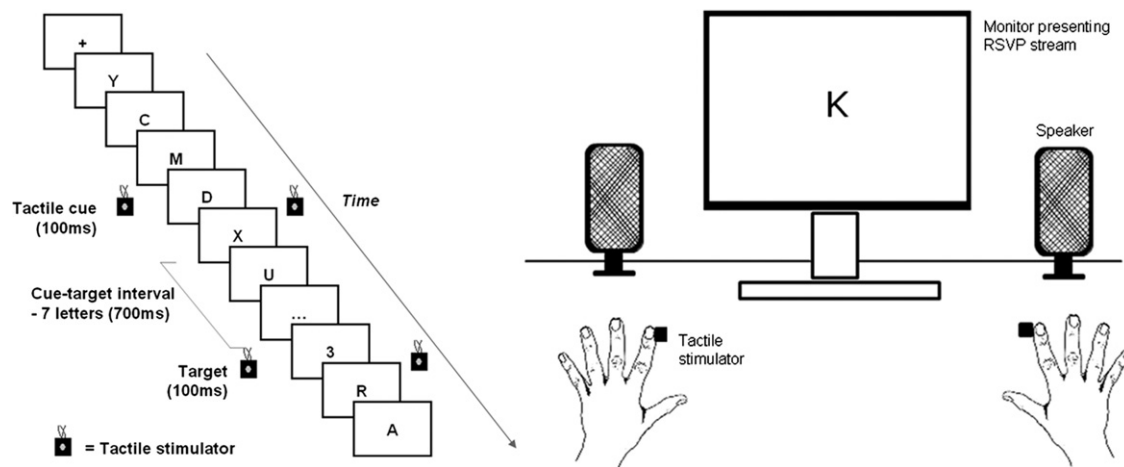


Fig. 1. Stimuli presentation and experimental set-up. *Left:* The sequence and time course of events for a typical trial. In both the single and dual task a tactile cue was presented to either the left or right hand. Following a 700 ms inter-stimulus interval either a number or a tactile target appeared (together with a letter) for 100 ms. In the single task the participant responded as rapidly as possible to the tactile target only and in the dual task the participant responded also if a number appeared on the screen. Visual and tactile targets were never presented together in the same trial. *Right:* Graphical representation of experimental set-up with monitor presenting the visual RSVP stream and visual targets. Tactile stimulators were attached to the left and right index fingers and hands were covered during the experiment.

12-V solenoids (5 mm in diameter), driving a metal rod with a blunt conical tip to the finger pad. The two tactile stimulators were fixed (using medical tape) to the left and right index finger and the hands were 640 mm apart. White noise (58 dB SPL) was continuously present through two speakers, each located in a direct line behind each hand, to mask any sounds made by the tactile stimulators. Tactile cues and targets consisted of a 100 ms single tap, thus, the contact time between rod and skin was 100 ms. The RSVP stream consisted of black letters (C, D, K, M, S, D, Y, P, X, R, B, Z, L, E, F, T, J, N) on a white background presented in the centre of a 15 in. monitor (Courier New font, point size 25, 7 mm on screen height) placed 60 cm in front of the participant. The numbers (2–9) embedded within the RSVP stream were of the same font and size as the letters. All letters and numbers were presented for 100 ms. Responses to both visual and tactile targets were made into a microphone, placed directly in front of the participant. A black cloth covered the participant's hands to eliminate any visual information of the tactile stimulation.

2.3. Design and procedure

Each trial consisted of a stream of 15 or 16 letters. Within this RSVP stream a tactile cue appeared to the left or right, which participants were instructed to ignore. In the single task, participants responded to the second tap (i.e., the tactile target) by saying *tap*. In the dual task the participant responded either to a tactile target to one of the hands or presentation of a number within the visual stream. Tactile and visual targets were never presented together in the same trial. Importantly, stimulus presentation was identical in both tasks. The only difference was that in the dual task participants were instructed to also respond to the visual targets in addition to the tactile targets.

The single and dual task consisted of six blocks of 88 trials each. Half of the participants performed the single task first and then the dual task, while the other half did the tasks in the reverse order. On every trial a tactile cue was presented. Following this cue, on 40 trials there was a tactile target, on 40 trials a visual target was presented and the remaining 8 trials were catch trials in which no number or tactile target was presented. The trials were randomly presented within each block. Out of the 40 trials with tactile targets, 20 trials were cued (cue and target presented to the same side) and 20 uncued (cue and target at opposite sides), and this was balanced across left and right. In total there were 120 cued and 120 uncued trials. Each participant completed a practice block consisting of 28 trials for each task, 12 with visual targets and 12 trials with tactile targets (6 cued and 6 uncued cued; that is, on the same or opposite side as the cue, respectively) and 4 catch trials. As the visual targets were presented centrally and not laterally, these were not cued or uncued in respect to the tactile cue location.

Each trial started with the presentation of three letters, each 100 ms in duration (see Fig. 1 for graphical representation of a trial). This was followed by the tactile cue to either the left or right, and simultaneous presentation of a fourth letter, both 100 ms in duration. Following the 100 ms tactile cue (which participants were instructed to ignore), seven letters were presented (inter-stimulus interval (ISI) of 700 ms) prior to the presentation of either a number for 100 ms or a tactile target to either the left or right hand for 100 ms. The target (tap or number) was followed by a sequence of three letters presented for 100 ms each. The tactile target stimuli were always presented together with a letter to not create a break in the letter stream presentation. In the single task, participants were instructed to ignore the visual display and responded when there was a tactile target by saying *tap* as rapidly as possible. In the dual task, participants

responded *tap* to the tactile targets and *screen* if presented with a number. The experimenter manually coded the response in the adjacent room, as the voice key only recorded the onset of the vocal response. Following the response (or if no response was made within 1500 ms) there was a random inter-trial interval (ITI) of 1700–2700 ms before the presentation of the next trial. A fixation cross was presented throughout the ITI.

To reduce the anticipation of when the cue would appear, half the trials had four instead of three letters prior to the cue presentation. That is, the duration from the start of the trial to tactile cue onset was 300 ms on half of the trials and 400 ms on the remaining trials. The cue-target interval was however always the same (700 ms).² Each trial of 15 letters was randomly selected out of a set of 20 different letter streams. The reason for not completely randomising the letter presentation was to avoid a letter being presented twice in one trial. In particular to avoid presenting the same letter one after the other and, therefore, it would be presented for, at least, 200 ms, as this may result in that letter appearing to “pop-out” in the RSVP stream. The numbers were randomly generated from trial to trial. The numbers were also presented during the single task, even though they did not require a response.

2.4. Behavioural analysis

Behavioural data were submitted to a 2×2 repeated-measures ANOVA with the factors Task (single, dual) and Cue (cued, uncued). A Task \times Cue interaction was followed up with paired samples *t*-test for each task separately. To compare RTs between modalities a paired samples *t*-test was conducted comparing RTs to visual targets and tactile targets (averaged over cued and uncued trials) in the dual task. Trials with RTs less than 100 ms and greater than 1200 ms were excluded from subsequent analysis, and in the dual task discrimination errors were also excluded. This led to the exclusion of less than 3% of trials in the single task and 7% in the dual task. Moreover, on average on 12.5% of the catch trials in the dual task an error was committed (incorrect responding to the catch trial). In the single task, less than 0.5% of errors were committed when participants responded when there was no tactile target.

2.5. ERP recording and analysis

Electroencephalography (EEG) was recorded using 32 Ag–AgCl electrodes mounted on an elastic cap (EASYCAP GmbH) and arranged according to the 10–20 system. A right earlobe reference was used during recording. Horizontal electro-oculogram (HEOG) was recorded from the outer canthi of the eyes. Electrode impedance was kept below 5 k Ω , earlobe and ground electrodes below 2 k Ω . Amplifier (BrainProducts GmbH) bandpass was 0.01–100 Hz and digitisation rate was 500 Hz. After recording, the EEG was digitally re-referenced to the average of the left and right earlobe and filtered with a low pass filter of 40 Hz. For the interval between the cue and target (which encompassed the *post-cue* and *cue-target interval* analysis) EEG was epoched offline into 900 ms periods starting

² This may have elicited a temporal expectation of when the target was to appear, however, the visual and tactile targets were both presented after the same interval to ensure any temporal expectation was identical in each task.

100 ms prior to cue onset and ending at target onset. For *post-target* ERP analysis, EEG was epoched offline into 300 ms periods starting 100 ms before the target and 200 ms after cue onset. The post-target time window was restricted to 200 ms post-target as we were particularly interested in modulations of early somatosensory attention effects (on the P45, N80, P100, N140 and early Nd components) by load and we expected contamination of later latencies by behavioural responses. Baseline correction was performed for both cue-target and post-target analysis time windows (100 ms period preceding onset of cue and target, respectively). Trials with eye movements (voltage exceeding $\pm 40 \mu\text{V}$ relative to baseline at HEOG electrodes) or with other artifacts (voltage exceeding $\pm 80 \mu\text{V}$ relative to baseline at all electrodes in the analysed intervals) were removed prior to EEG averaging. Additionally, the residual HEOG deflections were analysed to make sure no individual had a difference which exceeded $2.5 \mu\text{V}$ between cue-left and cue-right trials (see Kennett, van Velzen, Eimer, & Driver, 2007). Further, all trials with behavioural errors and catch trials were excluded from EEG analysis. This resulted in subsequent ERP analysis being based on an average of 234 trials in the dual task (less than 5% of trials removed) and 228 trials in the single task (less than 3% of trials removed).

The interval between the cue and target was subjected to two types of analyses; *post-cue* and *cue-target interval* ERP analysis. The *post-cue* analysis investigated the somatosensory components in the time window immediately following the cue (up to 350 ms after cue onset). The later *cue-target interval* analysis (400–800 ms post cue onset) investigated the lateralised effects of attentional orienting (i.e., presence of ADAN and LSN).

For *post-cue* analysis of somatosensory components³, ERPs were averaged separately for Task (single and dual) across cue side and ERP mean amplitudes were computed for measurement windows centred on the peak latencies, averaged across all conditions, of the somatosensory P45, N80, P100 and N140 components (40–60 ms, 70–90 ms, 90–120 ms and 120–150 ms post-stimulus, respectively). To investigate longer-latency effects of somatosensory processing differences between Tasks, mean amplitudes were also computed between 150–200 ms (Nd1) and 200–350 ms (Nd2) after cue onset. A repeated-measures ANOVA was conducted to compare perceptual load modulations with the factors Task (single, dual), Electrode Site (CP1/2, CP5/6, C3/4, FC1/2, FC5/6, T7/8) and Hemisphere (ipsilateral, contralateral). The electrode selection was based on electrodes close to and over somatosensory areas where attentional modulations of somatosensory ERPs are typically found (e.g., Eimer & Forster, 2003b; Jones & Forster, 2012).

For later *cue-target interval* analysis, ERPs were averaged separately for Task (single and dual) and Cue (cue left and cue right) and analysed at lateral anterior (F3/4, FC5/6, and F7/8), lateral central (C3/4, CP5/6 and T7/8), and lateral posterior sites (P3/4, P7/8, and O1/2). The selection of electrodes in the analysis was based on sites commonly used to investigate lateralized cue activity associated with the fronto-parietal attention network (see e.g., Gherri & Eimer, 2008). Mean amplitude values were computed for two post-cue time windows, that is 400–600 ms, and 600–800 ms (to confirm the presence of the ADAN and LSN component). These were subjected to separate repeated-measures ANOVAs with factors Cue (cue left, cue right), Hemisphere (left, right) and Electrode Site (F3/4, F7/8, FC5/6 for lateral anterior electrodes C3/4, CP5/6, T7/8 for lateral central electrodes and P3/4, P7/8, O1/2 for lateral posterior electrodes).

For *post-target* ERP analysis, epochs were averaged separately for task (single and dual) and cue type (cued, uncued). ERP mean amplitudes were computed for measurement windows centred on the peak latencies, averaged across all conditions, of the somatosensory P45, N80, P100 and N140 components (46–66 ms, 70–90 ms, 92–122 ms and 124–158 ms post-stimulus, respectively). To investigate mid to longer-latency effects of spatial attention, mean amplitudes were also computed between 160 and 200 ms (Nd1) after tactile stimulus onset. A repeated-measures ANOVA was conducted to compare attentional modulations with the factors Task (single, dual), Cue (cued, uncued), Electrode Site (CP1/2, CP5/6, C3/4, FC1/2, FC5/6, T7/8) and Hemisphere (ipsilateral, contralateral). The electrode selection for *post-target* analysis was the same as for *post-cue* analysis.

For all ANOVAs analysed in which the assumption of Sphericity was violated, Greenhouse–Geisser adjusted probability levels were reported. Interactions with the factor 'Electrode site' were not of interest as we did not set out to investigate differences of effects within the cluster of electrodes. That is, if there was a main effect of Cue, and also a Cue \times Electrode site interaction, then breaking down this interaction would add little relevant information, thus, the factor 'Electrode site', or interactions with 'Electrode site' will not be reported in Section 3.

To investigate whether IOR was directly linked to ERP modulations, we correlated (Pearson's r) the behavioural effect (cued minus uncued RTs) with ERP effects in the single task (cued minus uncued average amplitude differences).

3. Results

3.1. Behavioural performance

As evident from Fig. 2 behavioural performance showed a significant main effect of Task ($F(1,15)=69.21$, $p < .001$, $\eta_p^2=.82$) with faster RTs in the single (mean 314 ms, 97 standard deviation (SD)) compared to the dual task (477 ms, 124 SD). There was also a main effect of Cue ($F(1,15)=20.07$, $p < .001$, $\eta_p^2=.57$) and importantly, a significant Task \times Cue interaction ($F(1,15)=14.98$, $p=.002$, $\eta_p^2=.50$). Follow-up paired samples t -test for each task demonstrated significant IOR in the single task ($t(15)=-7.16$, $p < .001$) with faster RTs to target at uncued (303 ms, 96 SD) compared to cued locations (326 ms, 100 SD). There was no difference between uncued (475 ms, 125 SD) and cued trials (478 ms, 127 SD) in the dual task ($t < 1$). Moreover, responses to visual targets (616 ms, 123 SD) were significantly slower ($t(15)=-5.04$, $p < .001$) compared to tactile targets in the dual task (478 ms, 126 SD) (see Fig. 2).

3.2. ERP analyses

3.2.1. Post-cue analysis

In the *post-cue* ERP analysis, main effects and interactions including the factor 'Task' represented a difference of somatosensory processing of the irrelevant tactile stimulus (cue) that participants were instructed to ignore in the single versus dual task. Fig. 3 contrasts *post-cue* somatosensory ERPs in both tasks across cue side and shows larger positive amplitude for the single compared to dual task at the P100 component.

Analyses of the P45, N80, N140, Nd1, and Nd2 time windows showed no effect of Task, nor interactions including Task. Analysis of the P100 time window (90–120 ms) demonstrated a significant effect of Task ($F(1,15)=10.02$, $p=.006$, $\eta_p^2=.40$) with larger positivity for the single over dual task (see Fig. 3).

3.2.2. Cue-target interval analysis of lateralised ERPs

Figs. 4 and 5 show the presence of an ADAN and LSN components from 400 ms post cue onset to target onset at 800 ms, over anterior and central areas in both tasks. While Fig. 4 shows the ERP waveforms over anterior, central and posterior electrodes, Fig. 5 shows the corresponding topographical maps of ADAN and LSN distributions. The LSN is notably larger in the single compared to the dual task. In the subsequent analyses the presence of an ADAN or LSN is confirmed by a Cue \times Hemisphere interaction. An overview of the statistical outcomes is given in Table 1.

3.2.2.1. 400–600 ms cue-target interval time window. Anterior electrodes: Analysis of anterior electrodes showed a significant Cue \times Hemisphere interaction ($F(1,15)=33.72$, $p < .001$, $\eta_p^2=.69$) confirming an enhanced negativity for electrodes contralateral to Cue location. There was no Task \times Cue \times Hemisphere interaction.

Central electrodes: There was also a significant Cue \times Hemisphere interaction ($F(1,15)=27.00$, $p < .001$, $\eta_p^2=.64$).

Posterior electrodes: There were no Cue \times Hemisphere, nor a Task \times Cue \times Hemisphere interaction.

3.2.2.2. 600–800 ms cue-target interval time window. Anterior electrodes: Analysis of anterior electrodes showed a significant Task \times Cue \times Hemisphere interaction ($F(1,15)=15.02$, $p=.001$,

³ It should be noted that the ERPs recorded are not purely somatosensory as in both tasks a visual stream was concurrently presented. However, the ERPs in response to tactile stimuli were very similar to somatosensory ERPs recorded without visual stimulation (e.g., Jones & Forster, 2012). Importantly, all comparisons are across conditions with comparable visual contamination; therefore, any such potential influences unlikely explain the results reported here. Moreover, the topographical maps (Fig. 8) suggest the early effects (N80 and P100) originate from somatosensory areas as these are largest over central electrode.

$\eta_p^2=.50$, and also Cue \times Hemisphere ($F(1,15)=43.50$, $p<.001$, $\eta_p^2=.74$). Follow-up analysis for each task separately showed a Cue \times Hemisphere interaction in the single ($F(1,15)=45.09$, $p<.001$, $\eta_p^2=.75$) and dual task ($F(1,15)=28.69$, $p<.001$, $\eta_p^2=.66$). Thus, both tasks showed enhanced contralateral negativity while the LSN was significantly larger in the single compared to the dual task (see Fig. 4).

Central electrodes: There was a Cue \times Hemisphere interaction ($F(1,15)=53.46$, $p<.001$, $\eta_p^2=.78$) representing an LSN in both tasks.

Posterior electrodes: At posterior electrodes there was a Cue \times Hemisphere interaction ($F(1,15)=34.75$, $p<.001$, $\eta_p^2=.70$).

3.2.3. Post-target ERP analysis

Figs. 6 and 7 show ERPs in response to targets at the previously cued compared to uncued location in the 200 ms interval following the target in the single and dual task, respectively. Only in the single task an enhanced negativity for uncued over cued trials at electrodes contralateral to the target was present for the N80 component while the following components (P100, N140 and Nd1) are modulated by cue location in a similar way in both tasks. Fig. 8 shows the topographic distribution of the attention effects separate for each task. In the subsequent analyses the attention effect is represented by a main effect of Cue and the main statistical results are summarised in Table 2.

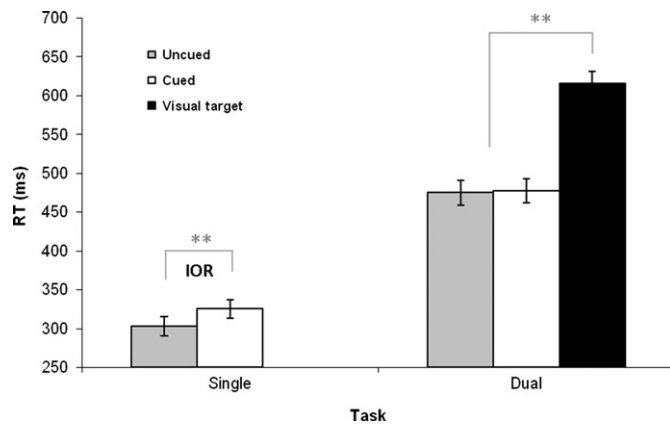


Fig. 2. Behavioural results. Average response times (RTs in ms) and standard error bars displayed for each condition in both task. Asterisks annotate significant differences between conditions (** $p<.001$). In the single task there was inhibition of return (IOR). In the dual task RTs to visual targets were on average slower than tactile targets, whilst there was no attention effect.

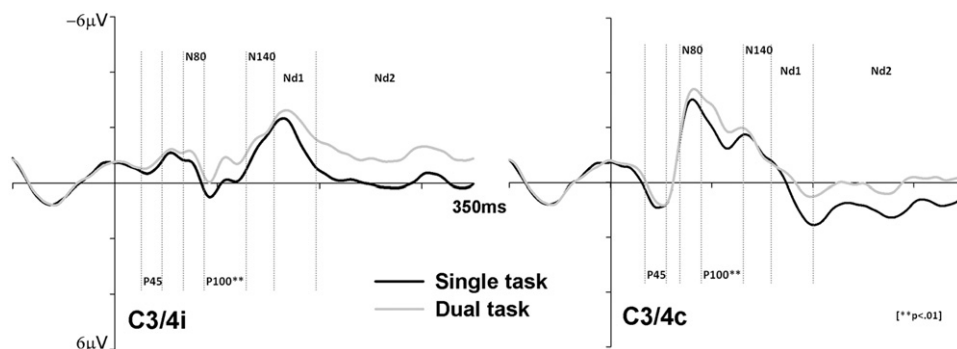


Fig. 3. Grand average post-cue ERPs for single (black line) and dual task (grey line), displayed at one representative electrode site, over the hemisphere contralateral (right pane) and ipsilateral (left pane) to the cue. Vertical dashed lines represent the time windows analysed (P45, N80, P100, N140, Nd1, and Nd2) and any significant task difference (P100) is denoted with an asterisk.

3.2.3.1. P45. Analysis of the P45 time window demonstrated no significant attention effect.

3.2.3.2. N80. Analysis of the N80 time window showed a Task \times Cue \times Hemisphere interaction ($F(1,15)=14.27$, $p=.002$, $\eta_p^2=.49$; as well as a Cue \times Hemisphere interaction, $F(1,15)=29.64$, $p<.001$, $\eta_p^2=.66$). The three-way interaction was broken down further and each task was analysed separately.

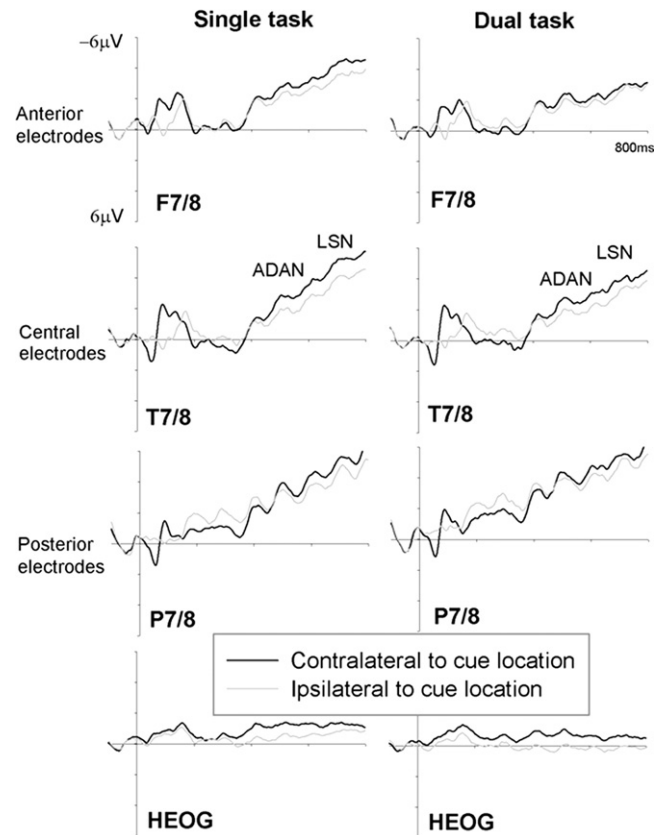


Fig. 4. Cue-target interval ERPs Grand-averaged ERP waveforms for the cue-target interval in the single (left panel) and dual task (right panel). Black lines represent ERPs at electrodes contralateral and grey lines represent ERPs at electrodes ipsilateral to the cue location. Enhanced negativity (upward deflections) for contralateral compared to ipsilateral electrodes, indicating the presence of the ADAN during middle (400–600 ms) and the LSN during the later (600–800 ms) part of the cue-target interval. The bottom two graphs represent the HEOG waveforms in each task.

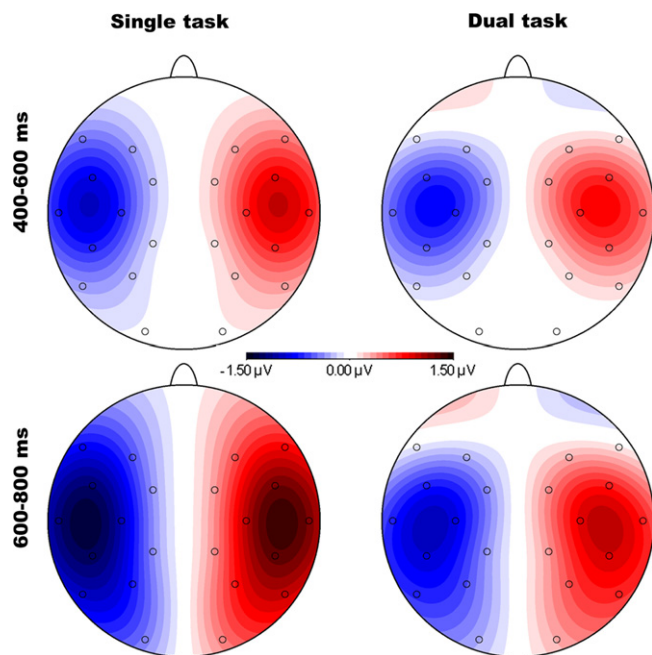


Fig. 5. Scalp distributions of cue-target interval data for the single (left) and dual task (right) for the 400–600 ms (top) and 600–800 ms (bottom) post cue onset intervals. Maps represent differences between brain activity observed over hemispheres ipsilateral and contralateral to the cue location. The obtained difference waveforms were mirrored to obtain symmetrical but inverse amplitude values for both hemispheres. That is, the same effect is presented over both left and right hemispheres in the figure. Amplitude range between -1.5 and $1.5 \mu\text{V}$.

Table 1
Summary of cue-target interval effects.

	Task	400–600 ms	600–800 ms
Lateralised Posterior electrodes P3/4, P7/8, O1/2	Single	n.s.	$p < .001$
Lateralised Central electrodes C3/4, CP5/6, T7/8	Single	$p < .001$	$p < .001$
Lateralised Anterior electrodes F3/F4, F7/F8, FC5/FC6	Single	$p < .001$	$p < .001$
	Dual		$p < .001$

Note. Summary of statistical results (probability levels (p) and non-significance (n.s.) stated) of lateralised cueing effects (Cue \times Hemisphere interaction stated) for the cue-target interval at three different scalp areas and at two time intervals during which the ADAN and LSN are commonly observed. Where there was a significant Task \times Cue \times Hemisphere interaction (at anterior sites in the 600–800 ms interval) the lateralised cueing effects are reported for each task separately. That is, there was a difference between single and dual task effects ($p = .001$) at anterior electrodes and follow-up analyses, reported in the table, showed significant LSN effects in both tasks, the task difference stems from larger LSN in the single task (see Section 3).

Analysis of the **single tasks** showed a significant Cue \times Hemisphere interaction ($F(1,15) = 53.10$, $p < .001$, $\eta_p^2 = .78$) and analysis of contralateral electrodes revealed a significant effect of Cue ($F(1,15) = 7.86$, $p = .013$, $\eta_p^2 = .34$) demonstrating enhanced negativity for uncued over cued trials. The N80 attention modulation was also present over ipsilateral electrodes (Effect of Cue; $F(1,15) = 4.58$, $p = .049$, $\eta_p^2 = .23$) with enhanced negativity for cued over uncued trials. Thus, the N80 was modulated by attention over both hemispheres in the single task.

Analysis of the N80 time window for the **dual task** demonstrated a Cue \times Hemisphere interaction ($F(1,15) = 8.43$, $p = .011$, $\eta_p^2 = .36$). However, separate follow-up analyses showed no attention effect over neither ipsilateral nor contralateral hemisphere. That is, there was no N80 attention modulation in the dual task.

3.2.3.3. P100. The overall analysis for the P100 showed no interactions including the factors Task and Cue together, however, there was a Cue \times Hemisphere interaction ($F(1,15) = 40.87$, $p < .001$, $\eta_p^2 = .73$), which was followed up with separate analysis for each hemisphere. Analysis of electrodes ipsilateral to target location showed a significant effect of Cue ($F(1,15) = 8.67$, $p < .001$, $\eta_p^2 = .37$). Contralateral hemisphere analysis also demonstrated a significant effect of Cue ($F(1,15) = 7.89$, $p = .013$, $\eta_p^2 = .35$) with enhanced positivity for cued compared to uncued trials in both tasks. Concluding, the P100 attention modulation was present over both hemispheres in both tasks.

3.2.3.4. N140. There was a main effect of Cue ($F(1,15) = 5.00$, $p = .041$, $\eta_p^2 = .25$) and also a Cue \times Hemisphere ($F(1,15) = 23.77$, $p < .001$, $\eta_p^2 = .61$). Follow-up analyses for each hemisphere showed a significant effect of Cue at ipsilateral electrodes ($F(1,15) = 16.94$, $p = .001$, $\eta_p^2 = .53$) whilst no effect of Cue at contralateral electrodes ($p > .7$).

3.2.3.5. Nd1. Analysis of the last time window showed a significant main effect of Cue ($F(1,15) = 16.19$, $p = .001$, $\eta_p^2 = .52$) with enhanced negativity for cued compared to uncued trials in both tasks

3.3. Analysis of the relationship between behavioural and ERP cueing effects

There were no significant correlations between the RT effect (IOR) in the single task and ERP cueing effects in the post target interval (Single task RT effect with: N80contra ($r = .20$, $p = .46$), N80ipsi ($r = .26$, $p = .36$), P100contra ($r = .301$, $p = .24$), P100ipsi ($r = .04$, $p = .89$), N140ipsi ($r = -.13$, $p = .63$), Nd1 $r = -.23$, $p = .40$)).

4. Discussion

The present study investigated the effects of engaging in a visual task upon exogenous tactile attention. Specifically, participants were performing a tactile exogenous attention task while either just watching a stream of visual letters (single task) or also detecting visual target digits within that stream (dual task). While behavioural responses showed that tactile exogenous attention effects are diminished when participants engaged in a visual task, ERP analyses revealed effects of visual engagement on somatosensory processing and tactile attentional orienting and selection. *Post-cue* ERP analysis showed that somatosensory processing is already attenuated at the P100 when engaging in a visual task. Furthermore, analysis of lateralised components, which reflect stages of attentional orienting, in the cue-target interval showed that the LSN was reduced when engaging in a visual task suggesting that preparatory activation of somatosensory areas is possibly attenuated. Finally, tactile post-target ERP analysis showed absence of attentional modulation of the post-target N80 component suggesting that visual engagement abolishes early attentional selection effects in touch. Taken together, ERP analyses revealed that engaging in a visual task affects relatively early somatosensory processing and diminishes multiple correlates of tactile exogenous attention.

In line with previous exogenous tactile attention studies (Brown, Danquah, Miles, Holmes, & Poliakoff, 2010; Cohen et al., 2005; Lloyd et al., 1999; Poliakoff et al., 2002; Miles, Poliakoff, & Brown, 2008; Röder et al., 2002, 2000, Jones & Forster, 2012), the behavioural results of the present study showed IOR in the single task with slower RTs to targets at previously cued compared to

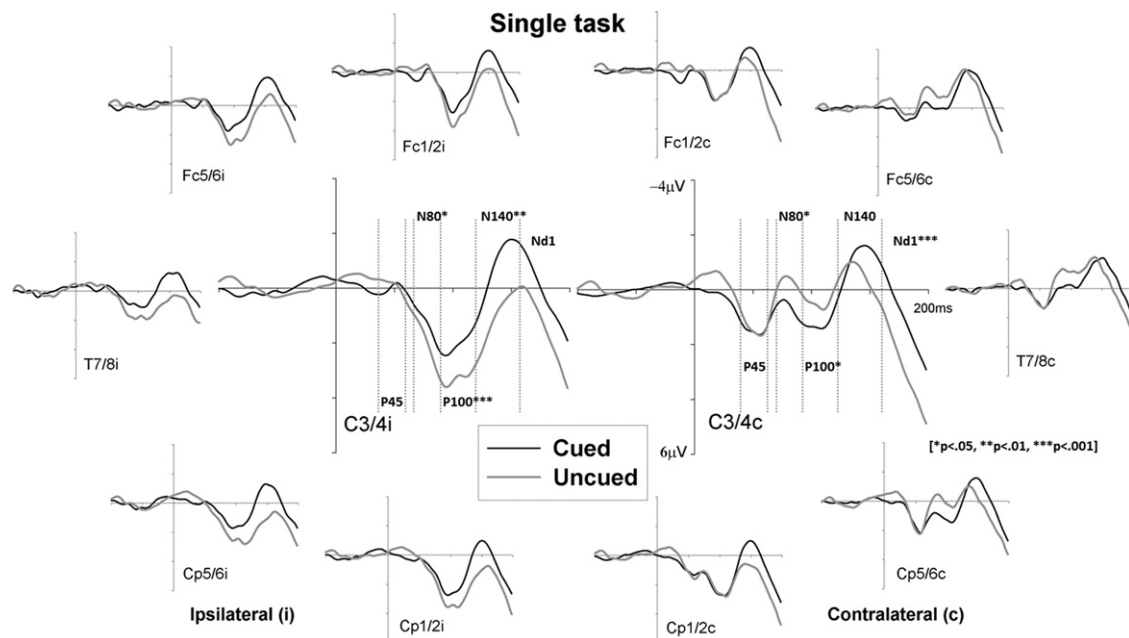


Fig. 6. Post-target ERPs in the single task. Single task grand averaged somatosensory ERPs elicited on cued (black lines) and uncued (grey lines) trials in the 200 ms following target onset. The left side of the figure shows ERPs elicited over electrodes ipsilateral to target side and the right side shows contralateral electrodes. Vertical dashed lines represent the time windows analysed (P45, N80, P100, N140, and Nd1) and any significant attention difference is denoted with asterisk(s).

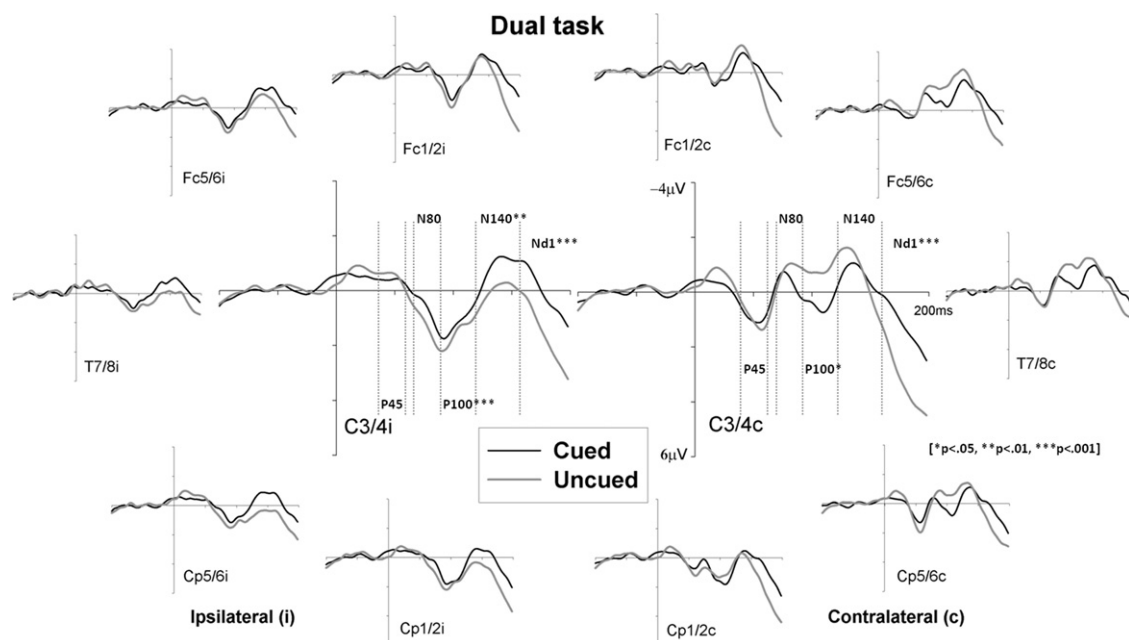


Fig. 7. Post-target ERPs in the dual task. Dual task grand averaged somatosensory ERPs elicited on cued (black lines) and uncued (grey lines) trials in the 200 ms following target onset. The left side of the figure shows ERPs elicited over electrodes ipsilateral to target side and the right side shows contralateral electrodes. Vertical dashed lines represent the time windows analysed (P45, N80, P100, N140, and Nd1) and any significant attention difference is denoted with an asterisk.

uncued locations. Importantly, this effect was abolished when also engaging in a visual task (see Fig. 2). In addition, RTs were slower in the dual than single task. In both tasks participants were responding to tactile targets but in the dual task on half of the trials participants responded also to visual targets. Thus, the slowing of responses might indicate that the irrelevant tactile cue is less alerting under dual task conditions, and further, that the tactile cues might either capture attention less effectively under dual task conditions in line with the load theory (Lavie, 1995; Lavie et al., 2004). That exogenous attention effects are diminished under dual task conditions has also been shown for

facilitatory tactile (Santangelo & Spence, 2007), visual (e.g., Santangelo et al., 2011) and auditory (e.g., Santangelo, van der Lubbe, Belardinelli, & Postma, 2008) exogenous attention effects, and for dual tasks within the same modality (e.g., vision, Santangelo et al., 2011) and across modalities (vision and touch, e.g., Santangelo & Spence, 2007; vision and auditory, e.g., Santangelo et al., 2008). This study therefore extends these findings to show that inhibitory tactile exogenous attention effects (i.e., IOR) can also be diminished under dual task conditions. However, it should be noted that, when considering behavioural results, reduced IOR in the dual task is not necessarily

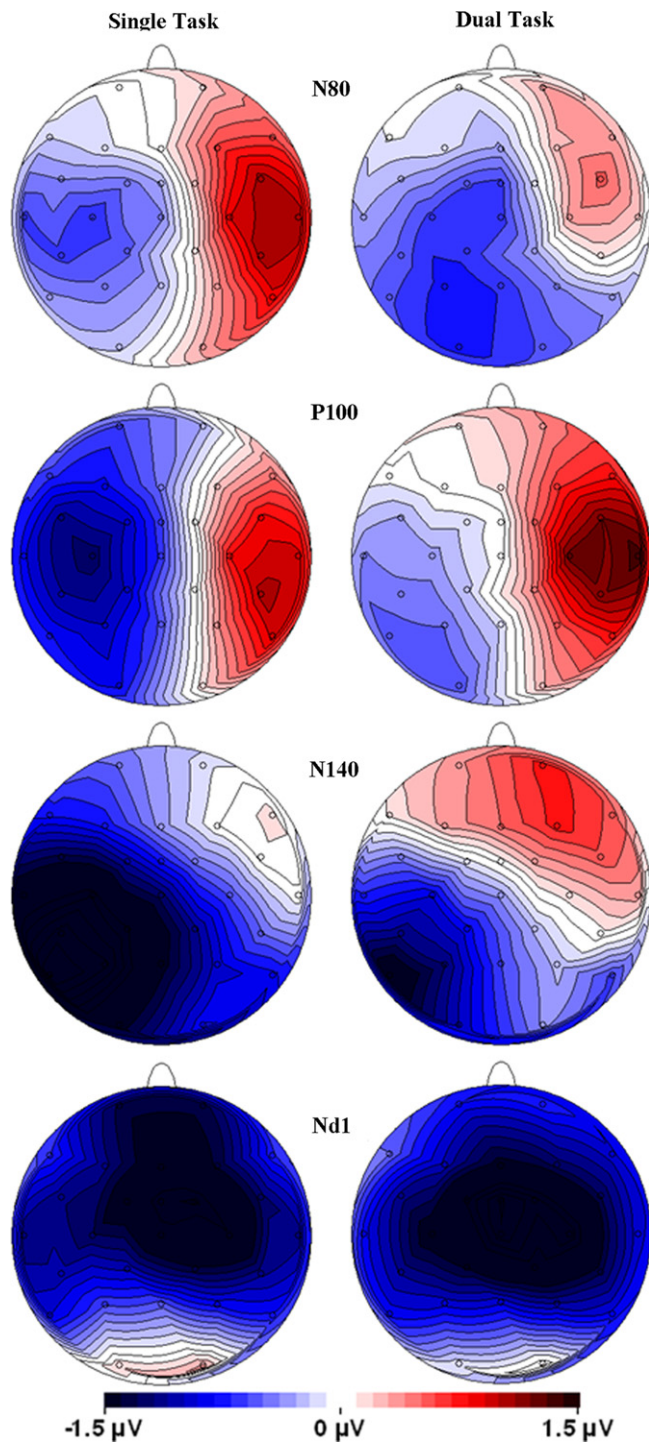


Fig. 8. Topographic maps of the post-target attention effects (ERPs on uncued were subtracted from cued trials) at each time window analysed, which showed an attention effect presented for the single (left panel) and dual task (right panel). The right hemisphere shows attention effects contralateral to the target side and the left hemisphere shows ipsilateral attention effects in each task.

synonymous with reduced exogenous attention effects as mounting evidence now suggests IOR to be at least partly dissociable from attention (see Lupianez, 2010 for a comprehensive review on this issue). For example, it has been demonstrated that IOR can occur at attended locations when attention never disengages between cue and target, which strongly suggests a spotlight theory of attention cannot solely explain IOR (e.g., Chica,

Lupianez, & Bartolomeo, 2006; Chica, Sanabria, Lupiáñez, & Spence, 2007). Alternative accounts of IOR are primarily based upon vision research. For example Taylor & Klein, (2000) suggested two flavours of IOR whereby an attentional/perceptual IOR is activated when the oculomotor system is actively suppressed and a more motoric flavour when actively engaged. Satel, Hilchey, Wang, Story, and Klein (2013) recently demonstrated that the P1 cueing effect was only correlated with IOR when the oculomotor system was actively suppressed. The present study does not lend itself well to directly assess the nature of IOR and moreover whether IOR in touch is similar to vision. The oculomotor system in our study was actively suppressed in that participants fixated their gaze on a central cross, however, we did not find a correlation between IOR and P100 amplitude cueing effect in the single task. Understanding the underlying mechanisms of IOR in touch may be better achieved in a paradigm which employs several cue-target intervals. Moreover, in the context of two flavours of IOR and whether this translates to touch it may be more relevant to investigate IOR during active and passive hand movements.

RTs to targets provide only one measure of exogenous attention and/or IOR while concurrently recorded ERPs allow tracking of tactile cue processing and cue elicited attention effects. Therefore, the ERP analyses investigated how increasing task demands affected processing of tactile stimuli and tactile attention. In particular the aim of recording ERPs was to track the effects of engagement in a visual task on somatosensory processing and on attentional spatial orienting and target selection. To probe the state of somatosensory cortex with and without visual engagement early *post-cue* ERPs were compared, while to understand visual engagement effects on attentional orienting and selection *cue-target interval* and *post-target* ERPs were contrasted for cueing effects in the single and dual tasks.

Comparison of *post-cue* ERPs in the single and dual task revealed differences in somatosensory processing in the two tasks; that is, a significantly reduced positivity in the dual compared to the single task already at the P100 component (see Fig. 3). The mid-latency somatosensory P100 is assumed to be generated in bilateral secondary somatosensory cortex (Tarkka, Micheloyannis, & Stokić, 1996; Valeriani, Fraioli, Ranghi, & Giaquinto, 2001; Frot, Garcia-Larrea, Guénot, & Mauguière, 2001; Mauguière et al., 1997; Zhu, Disbrow, Zumer, McGonigle, & Nagarajan, 2007). Our findings therefore suggest that visual engagement modulates somatosensory processing, at least, within secondary somatosensory cortex. This is in line with research on the effects of load on peripheral distractor processing in vision. Studies using fMRI (e.g., Rees, Frith, & Lavie, 1997; Schwartz et al., 2005) and electrophysiological recordings (e.g., Fu, Fedota, Greenwood, & Parasuraman, 2010; Handy, Soltani, & Mangun, 2001; Rauss et al., 2009, O'Connell, Schneider, Hester, Mattingley & Bellgrove, 2011) have shown decreased sensory processing in primary and secondary visual cortex for irrelevant peripheral stimuli when increasing central task load. In particular, an ERP study by Handy et al. (2001) showed a reduced P1 for irrelevant peripheral stimuli with increased perceptual load of a foveal task. Taken together, this suggests that increased load in a central visual task does not only affect early stages of visual but also of tactile processing. Furthermore, Smith, Singh & Greenlee (2000) suggested that spatial attention to a central location may reduce the baseline activity of neurons with receptive fields outside that location in the visual field. In light of our findings this may suggest that engaging in a central visual task also leads to suppression of peripheral somatosensory processing possibly through reduction in baseline activity of somatosensory neurons. Further research would be needed to reveal the exact mechanism underlying the crossmodal effect found in the present study

Table 2
Post-target ERP attention effects.

Component	N80		P100		N140		Nd1
	Contra.	Ipsi.	Contra.	Ipsi.	Contra.	Ipsi.	Bilateral
Single task	$p=.013$	$p=.049$	$p=.013$	$p<.001$	n.s.	$p=.001$	$p=.001$
Dual task	n.s.	n.s.					

Note. Summary of statistical results (probability levels (p) and non-significance (n.s.) stated) of post-target ERP attention effects (cued vs. uncued trials). For components where there was a significant Cue \times Hemisphere interaction, separate analysis of Cue was conducted for each hemisphere (contra and ipsilateral to target location), otherwise stated as bilateral if attention effect present over both hemispheres. Where there was a Task \times Cue interaction, further separate analysis for each task has been conducted (N80).

(see also Mozolic et al., 2008) and whether a central tactile instead of a visual task would result in similar suppression of tactile peripheral stimulation.

To explore the effect of visual engagement on lateralised components during the cue-target interval ERPs in response to task irrelevant tactile cues applied to the right and left hand were contrasted in the 400–800 ms interval after cue onset (see Figs. 4 and 5). For this, cue elicited activity over the hemisphere contralateral to the cued side was compared to ipsilateral activity in the single and dual tasks. Based on previous studies of tactile attention (Forster et al., 2009; Gherri & Forster, 2012; Jones & Forster, 2012) we expected to find an ADAN followed by a LSN. The ADAN has been suggested to reflect supramodal endogenous attention mechanisms in the frontal areas (e.g., Eimer, van Velzen, & Driver, 2002; Forster et al., 2009; Seiss, Gherri, Eardley, & Eimer, 2007). Recently, we demonstrated an exogenous ADAN in the cue-target interval following exogenous tactile cues (Jones & Forster, 2012). In line with our previous finding, in the present study an exogenous ADAN was elicited over anterior and central electrodes in the single and dual tasks. In other words, the present study replicated our previous findings that exogenous cues can elicit activation in the fronto-parietal attention network, previously only suggested to reflect endogenous attention. In tactile attention studies when only a somatotopic reference frame is employed (cf. van Velzen, Eardley, Forster, & Eimer, 2006) the ADAN is followed by continued enhanced negativity over electrodes contralateral compared to ipsilateral to the cued side, which recently was suggested to reflect preparatory activity in somatosensory areas, the LSN (Gherri & Forster, 2012). Like in previous tactile spatial attention studies (e.g., Gherri & Eimer, 2008; Eimer, Forster, & van Velzen, 2003; Forster et al., 2009; Jones & Forster, 2012; van Velzen, Forster, & Eimer, 2002; van Velzen, et al., 2006) the LSN follows on from the ADAN. For this reason, this component has previously been labelled 'late ADAN'. However, in a very recent study from our lab (Gherri & Forster, 2012) we found that when participants crossed their arms, and thus external and somatotopic reference frames are misaligned, instead of an enhanced negativity contralateral to the cued side an enhanced positivity was present contralateral to the cued side for the later part of the cue-target interval (LSN) while the earlier part (ADAN) did not show such a reversal. Since in the present study the hands were placed in their corresponding hemispace we did not expect a difference between the ADAN and LSN component and thus it is difficult to clearly establish when the ADAN ends and LSN begins. However, we assume, based on the previous finding by Gherri and Forster (2012), that the late part of the cue target interval is related to the LSN rather than a late ADAN. Interestingly, the magnitude of the LSN was significantly smaller in the dual compared to the single task. This indicates that additional engagement in a visual task, not only modulated somatosensory processing of task irrelevant tactile stimuli (i.e., cues), but may also have attenuated preparatory activity in somatosensory areas

in anticipation of tactile stimulus processing. It should be noted that there are small HEOG deviations in both tasks (Fig. 4); however, if anything, the HEOG deviation in the LSN time window is larger in the dual than in the single task. The LSN topography is largely central suggesting somatosensory areas are primarily active but future studies may wish to explore the exact underlying sources of this cue-target component.

The final ERP analysis explored the more commonly investigated ERP waveforms which show the components and processing stages that are modulated by attentional selection in the post-target time window. Attention modulations of these ERPs reflect selective attention to target processing, with typically larger ERP amplitudes for attended locations (e.g., Luck, Woodman, & Vogel, 2000). The main difference between the two tasks in terms of post-target ERPs was the attention modulation of the N80 in the single but not dual task (see Figs. 6 and 7 for ERP waveforms and Fig. 8 for a topographical representation of the N80 effects). This difference demonstrated that exogenous attention and additional visual engagement interacted at early somatosensory processes, likely primary somatosensory cortex (Allison, McCarthy, & Wood, 1992; Allison et al., 1989; Forss & Jousmäki, 1998; Hari & Forss, 1999; Hari et al., 1984; Inui et al., 2004; Mima, Nagamine, Nakamura, & Shibasaki, 1998). The N80 component has, in a couple of studies, been shown to be modulated by endogenous tactile attention with enhanced negativity for attended over unattended stimuli (Eimer & Forster, 2003a; Michie, Bearpark, Crawford, & Glue, 1987). Moreover, the N80 in the single task replicated our previous exogenous attention finding, with larger amplitude for tactile stimuli at uncued over cued locations in a simple detection task (Jones & Forster, 2012). It is likely that the N80 effect reflects an exogenous modulation driven by the lateralised cues. That there was no N80 attention modulation in the dual task further supports the conclusion that somatosensory processing is attenuated, as seen in the diminished post-cue and preparatory effects when engaging in a visual task. The earliest exogenous attention modulation for the dual task was at the P100 component suggesting that in touch early exogenous effects are abolished when also engaging in a visual task. In vision, perceptual load has been shown to affect spatial based selection within extrastriate areas, through interactions of attention and perceptual load at the P1 (Handy & Mangun, 2000) and P1m (peak latency at around 100–140 ms over midline electrodes; Fu et al., 2010). The present post-target ERP results may therefore indicate that engaging in an additional visual task, and thus, increased load can abolish tactile selective attention modulations of primary somatosensory cortex (N80) whilst in vision, perceptual load interacts with selective attention at a slightly later stage of processing, namely in extrastriate cortical areas. Finally, our finding that endogenously engaging in a visual task modulates correlates of tactile attentional selection is in line with a supramodal account of attention (Eimer & Driver, 2001).

Following the N80, the P100, N140 and Nd1 were modulated similarly by attention in both tasks. The P100 is suggested to be a bilateral component originating in secondary somatosensory cortex (Frot et al., 2001; Mauguière et al., 1997; Zhu et al., 2007) while the origin of the N140 is less clear with multiple areas suggested (Garcia-Larrea, Lukaszewicz, & Mauguière, 1995), in particular the secondary somatosensory cortex and frontal areas (Allison et al., 1992; Hari & Forss, 1999; Hari et al., 1984; Kakigi et al., 2000; Mima et al., 1998). These two components have repeatedly been demonstrated to be modulated by endogenous tactile attention (P100; Adler, Giabbiconi, & Müller, 2009; Eimer & Forster, 2003a, 2003b; Zopf, Giabbiconi, Gruber, & Müller, 2004), N140; (Adler et al., 2009; Eimer & Forster, 2003a; Forster & Eimer, 2004; Zopf et al., 2004). The similarity of attention modulations of the P100, N140 and Nd1 in single and dual tasks suggests that attention effects on these components, and thus on mid and later stages of somatosensory target processing are, if anything, little affected by engagement in an additional visual task.

In summary, this study demonstrated multiple effects of engaging in a visual task on behavioural and ERP correlates of exogenous tactile attention. Behavioural results showed diminished exogenous attention effects (IOR) under dual task conditions. In addition, concurrently recorded ERPs were compared in the single and the dual tasks in order to reveal how visual engagement affected somatosensory processing and correlates of exogenous attention. First, analysis of *post-cue* ERPs demonstrated modulation of somatosensory processing as early as the P100 across tasks showing that somatosensory processing is modulated at a relatively early stage by engagement in a visual task. Further, this extends comparable neuroimaging studies in the visual modality (e.g., Schwartz et al., 2005) to show that engaging in a visual task modulates processing of task irrelevant tactile stimuli in secondary somatosensory cortex, as indicated by the task modulation of the P100. Second, analysis of the *cue-target interval* demonstrated an ADAN and LSN in both single and dual tasks. However, the LSN was larger in the single versus dual task possibly indicating that preparatory activation of somatosensory areas is reduced prior to target presentation when additionally engaged in a visual task. Finally, correlates of selective attention in the *post-target* interval showed attentional modulation of the N80 in the single whilst not in the dual task, suggesting that not only somatosensory processing but also tactile attentional selection mechanisms are altered when monitoring a visual stream during an exogenous attention task. To conclude, we show that engaging in a visual task attenuates several indices of processing tactile stimuli.

References

Adler, J., Giabbiconi, C.-M., & Müller, M. M. (2009). Shift of attention to the body location of distracters is mediated by perceptual load in sustained somatosensory attention. *Biological Psychology*, 81(2), 77–85.

Allison, T., McCarthy, G., & Wood, C. C. (1992). The relationship between human long-latency somatosensory evoked potentials recorded from the cortical surface and from the scalp. *Electroencephalography and Clinical Neurophysiology*, 84(4), 301–314.

Allison, T., McCarthy, G., Wood, C. C., Darcey, T. M., Spencer, D. D., & Williamson, P. D. (1989). Human cortical potentials evoked by stimulation of the median nerve. Cytoarchitectonic areas generating short-latency activity. *Journal of Neurophysiology*, 62(3), 694–710.

Brown, R. J., Danquah, A. N., Miles, E., Holmes, E., & Poliakoff, E. (2010). Attention to the body in nonclinical somatoform dissociation depends on emotional state. *Journal of Psychosomatic Research*, 69(3), 249–257.

Chica, A. B., Lupianez, J., & Bartolomeo, P. (2006). Dissociating inhibition of return from endogenous orienting of spatial attention: evidence from detection and discrimination tasks. *Cognitive Neuropsychology*, 23(7), 1015–1034.

Chica, A. B., Sanabria, D., Lupiáñez, J., & Spence, C. (2007). Comparing intramodal and crossmodal cuing in the endogenous orienting of spatial attention. *Experimental Brain Research*, 179(3), 353–364.

Cohen, J. C., Bolanowski, S. J., & Verrillo, R. T. (2005). A direct comparison of exogenous and endogenous inhibition of return and selective attention mechanisms in the somatosensory system. *Somatosensory & Motor Research*, 22(4), 269–279.

Eimer, M., & Driver, J. (2001). Crossmodal links in endogenous and exogenous spatial attention: evidence from event-related brain potential studies. *Neuroscience and Biobehavioural Review*, 25(6), 497–511.

Eimer, M., & Forster, B. (2003a). Modulations of early somatosensory ERP components by transient and sustained spatial attention. *Experimental Brain Research*, 151(1), 24–31.

Eimer, M., & Forster, B. (2003b). The spatial distribution of attentional selectivity in touch: evidence from somatosensory ERP components. *Clinical Neurophysiology*, 114(7), 1298–1306.

Eimer, M., Forster, B., & van Velzen, J. (2003). Anterior and posterior attentional control systems use different spatial reference frames: ERP evidence from covert tactile-spatial orienting. *Psychophysiology*, 40, 924–933.

Eimer, M., van Velzen, J., & Driver, J. (2002). Cross-modal interactions between audition, touch, and vision in endogenous spatial attention: ERP evidence on preparatory states and sensory modulations. *Journal of Cognitive Neuroscience*, 14(2), 254–271.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a non-search task. *Perception and Psychophysics*, 16, 143–149.

Forss, N., & Jousmäki, V. (1998). Sensorimotor integration in human primary and secondary somatosensory cortices. *Brain Research*, 781(1–2), 259–267.

Forster, B., Sambo, C. F., & Pavone, E. F. (2009). ERP correlates of tactile spatial attention differ under intra- and intermodal conditions. *Biological Psychology*, 82(3), 227–233.

Frot, M., Garcia-Larrea, L., Guénot, M., & Mauguière, F. (2001). Responses of the supra-sylvian (SII) cortex in humans to painful and innocuous stimuli. A study using intra-cerebral recordings. *Pain*, 94(1), 65–73.

Fu, S., Fedota, J. R., Greenwood, P. M., & Parasuraman, R. (2010). Dissociation of visual C1 and P1 components as a function of attentional load: an event-related potential study. *Biological Psychology*, 85(1), 171–178.

Garcia-Larrea, L., Lukaszewicz, A. C., & Mauguière, F. (1995). Somatosensory responses during selective spatial attention: the N120-to-N140 transition. *Psychophysiology*, 32, 526–537.

Gherri, E., & Eimer, M. (2008). Links between eye movement preparation and the attentional processing of tactile events: an event-related brain potential study. *Clinical Neurophysiology*, 119(11), 2587–2597.

Gherri, E., & Forster, B. (2012). Crossing the hands disrupts tactile spatial attention but not motor attention: evidence from event-related potentials. *Neuropsychologia*, 50(9), 2303–2316.

Green, J. J., & McDonald, J. J. (2006). An event-related potential study of supramodal attentional control and crossmodal attention effects. *Psychophysiology*, 43(2), 161–171.

Handy, T. C., & Mangun, G. R. (2000). Attention and spatial selection: electrophysiological evidence for modulation by perceptual load. *Perception & Psychophysics*, 62(1), 175–186.

Handy, T. C., Soltani, M., & Mangun, G. R. (2001). Perceptual load and visuocortical processing: event-related potentials reveal sensory-level selection. *Psychological Science*, 12(3), 213–218.

Hari, R., & Forss, N. (1999). Magnetoencephalography in the study of human somatosensory cortical processing. *Philosophical Transactions of the Royal Society of London Series B: Biological Sciences*, 354(1387), 1145–1154.

Hari, R., Reinikainen, K., Kaukoranta, E., Hamalainen, M., Ilmoniemi, R., Penttinen, A., et al. (1984). Somatosensory evoked cerebral magnetic fields from SI and SII in man. *Electroencephalography and clinical Neurophysiology*, 57(3), 254–263.

Hopf, J. M., & Mangun, G. R. (2000). Shifting visual attention in space: an electrophysiological analysis using high spatial resolution mapping. *Clinical Neurophysiology*, 111(7), 1241–1257.

Inui, K., Wang, X., Tamura, Y., Kaneoke, Yoshiki, & Kakigi, Ryusuke. (2004). Serial processing in the human somatosensory system. *Cerebral Cortex*, 14(8), 851–857.

Jones, A., & Forster, B. (2012). Reflexive attention in touch: an investigation of event related potentials and behavioural responses. *Biological Psychology*, 89, 313–322.

Kakigi, R., Hoshiyama, M., Shimojo, M., Naka, D., Yamasaki, H., Watanabe, S., et al. (2000). The somatosensory evoked magnetic fields. *Progress in Neurobiology*, 61(5), 495–523.

Kennett, S., van Velzen, J., Eimer, M., & Driver, J. (2007). Disentangling gaze shifts from preparatory ERP effects during spatial attention. *Psychophysiology*, 44, 69–78.

Klein, M. (2000). Inhibition of return. *Trends in Cognitive Sciences*, 4(4), 138–146.

Klemen, J., Buchel, C., Buhler, M., Menz, M. M., & Rose, M. (2010). Auditory working memory load impairs visual ventral stream processing: toward a unified model of attentional load. *Journal of Cognitive Neuroscience*, 22(3), 437–446.

Klemen, J., Buchel, C., & Rose, M. (2009). Perceptual load interacts with stimulus processing across sensory modalities. *European Journal of Neuroscience*, 29, 2426–2434.

Lavie, N. (1995). Perceptual load as a necessary condition for selective attention. *Journal of Experimental Psychology: Human Perception and Performance*, 21(3), 451–468.

Lavie, N., Hirst, A., de Fockert, J. W., & Viding, E. (2004). Load theory of selective attention and cognitive control. *Journal of Experimental Psychology General*, 133(3), 339–354.

- Lloyd, D. M., Bolanowski, S. J., Jr, Howard, L., & McGlone, F. (1999). Mechanisms of attention in touch. *Somatosensory & Motor Research*, 16(1), 3–10.
- Luck, S., Woodman, G., & Vogel, E. (2000). Event-related potential studies of attention. *Trends in Cognitive Sciences*, 4(11), 432–440.
- Lupianez, J. (2010). Inhibition of return. In: A. C. Nobre, & J. T. Coull (Eds.), *Attention and time* (pp. 17–34). Oxford: Oxford University Press.
- Mauguière, F., Merlet, I., Forss, N., Vanni, S., Jousmäki, V., Adeleine, P., et al. (1997). Activation of a distributed somatosensory cortical network in the human brain. A dipole modelling study of magnetic fields evoked by median nerve stimulation. Part I: Location and activation timing of SEF sources. *Electroencephalography and Clinical Neurophysiology*, 104(4), 281–289.
- Michie, P. T., Bearpark, H. M., Crawford, J. M., & Glue, L. C. (1987). The effects of spatial selective attention on the somatosensory event-related potential. *Psychophysiology*, 24, 449–463.
- Miles, E., Poliakoff, E., & Brown, R. J. (2008). Investigating the time course of tactile reflexive attention using a non-spatial discrimination task. *Acta Psychologica*, 128(2), 210–215.
- Mima, T., Nagamine, T., Nakamura, K., & Shibasaki, H. (1998). Attention modulates both primary and second somatosensory cortical activities in humans: a magnetoencephalographic study. *Journal of Neurophysiology*, 80(4), 2215–2221.
- Mozolic, J. L., Joyner, D., Hugenschmidt, C. E., Peiffer, A. M., Kraft, R. A., Maldjian, J. A., et al. (2008). Cross-modal deactivations during modality-specific selective attention. *BMC Neurology*, 8, 35.
- Nobre, A. C., Sebestyen, G. N., & Miniussi, C. (2000). The dynamics of shifting visuospatial attention revealed by event related brain potentials. *Neuropsychologia*, 38, 964–974.
- O'Connell, R. G., Schneider, D., Hester, R., Mattingley, J. B., & Bellgrove, M. A. (2011). Attentional load asymmetrically affects early electrophysiological indices of visual orienting. *Cerebral Cortex*, 21(5), 1056–1065.
- Poliakoff, E., Spence, C., McGlone, F. P., & Cody, F. W. J. (2002). Tactile inhibition of return: non-ocular response inhibition and mode of response. *Experimental Brain Research*, 146(1), 54–59.
- Praamstra, P., Boutsen, L., & Humphreys, G. W. (2005). Frontoparietal control of spatial attention and motor intention in human EEG. *Journal of Neurophysiology*, 94, 764–774.
- Rauss, K. S., Pourtois, G., Vuilleumier, P., & Schwartz, S. (2009). Attentional load modifies early activity in human primary visual cortex. *Human Brain Mapping*, 30(5), 1723–1733.
- Rees, G., Frith, C. D., & Lavie, N. (1997). Modulating irrelevant motion perception by varying attentional load in an unrelated task. *Science*, 278(5343), 1616–1619.
- Röder, B., Spence, C., & Rösler, F. (2000). Inhibition of return and oculomotor control in the blind. *NeuroReport*, 11(13), 3043–3045.
- Röder, B., Spence, C., & Rösler, F. (2002). Assessing the effect of posture change on tactile inhibition-of-return. *Experimental Brain Research*, 143(4), 453–462.
- Santangelo, V., Belardinelli, M. O., & Spence, C. (2007). The suppression of reflexive visual and auditory orienting when attention is otherwise engaged. *Journal of Experimental Psychology: Human Perception and Performance*, 33(1), 137–148.
- Santangelo, V., Botta, F., Lupiáñez, J., & Spence, C. (2011). The time course of attentional capture under dual-task conditions. *Attention, Perception, & Psychophysics*, 73(1), 15–23.
- Santangelo, V., & Spence, C. (2007). Assessing the automaticity of the exogenous orienting of tactile attention. *Perception*, 36(10), 1497–1505.
- Santangelo, V., & Spence, C. (2008). Is the exogenous orienting of spatial attention truly automatic? Evidence from unimodal and multisensory studies. *Consciousness and Cognition*, 17(3), 989–1015.
- Santangelo, V., van der Lubbe, R. H. J., Belardinelli, M. O., & Postma, A. (2008). Multisensory integration affects ERP components elicited by exogenous cues. *Experimental Brain Research*, 185, 269–277.
- Satel, J., Hilchey, M. D., Wang, Z., Story, R., & Klein, R. M. (2013). The effects of ignored versus foveated cues upon inhibition of return: An event-related potential study. *Attention Perception & Psychophysics*, 75, 29–40.
- Schwartz, S., Vuilleumier, P., Hutton, C., Maravita, A., Dolan, R. J., & Driver, J. (2005). Attentional load and sensory competition in human vision: modulation of fMRI responses by load at fixation during task-irrelevant stimulation in the peripheral visual field. *Cerebral Cortex*, 15(6), 770–786.
- Seiss, E., Gherri, E., Eardley, A. F., & Eimer, M. (2007). Do ERP components triggered during attentional orienting represent supramodal attentional control? *Psychophysiology*, 44(6), 987–990.
- Smith, A. T., Singh, K. D., & Greenlee, M. W. (2000). Attentional suppression of activity in the human visual cortex. *NeuroReport*, 11, 271–277.
- Spalek, T. M., Falcon, L. J., & Di Lollo, V. (2006). Attentional blink and attentional capture: endogenous versus exogenous control over paying attention to two important events in close succession. *Perception & Psychophysics*, 68(4), 674–684.
- Tarkka, I., Micheloyannis, S., & Stokić, D. (1996). Generators for human P300 elicited by somatosensory stimuli using multiple dipole source analysis. *Neuroscience*, 75(1), 275–287.
- Taylor, T. L., & Klein, R. M. (2000). Visual and motor effects in inhibition of return. *Journal of Experimental Psychology: Human Perception and Performance*, 26, 1639–1656.
- Valeriani, M., Fraioli, L., Ranghi, F., & Giaquinto, S. (2001). Dipolar source modelling of the P300 event-related potential after somatosensory stimulation. *Muscle & Nerve*, 24(12), 1677–1686.
- van Velzen, J., Eardley, A. F., Forster, B., & Eimer, M. (2006). Shifts of attention in the early blind: an ERP study of attentional control processes in the absence of visual spatial information. *Neuropsychologia*, 44(12), 2533–2546.
- van Velzen, J., Forster, B., & Eimer, M. (2002). Temporal dynamics of lateralized ERP components elicited during endogenous attentional shifts to relevant tactile events. *Psychophysiology*, 39, 874–878.
- Zhu, Z., Disbrow, E. a, Zumer, J. M., McGonigle, D. J., & Nagarajan, S. S. (2007). Spatiotemporal integration of tactile information in human somatosensory cortex. *BMC Neuroscience*, 8, 21.
- Zopf, R., Giabbiconi, C. M., Gruber, T., & Müller, M. M. (2004). Attentional modulation of the human somatosensory evoked potential in a trial-by-trial spatial cueing and sustained spatial attention task measured with high density 128 channels EEG. *Cognitive Brain Research*, 20(3), 491–509.