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Highlights

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

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► We tracked how visual engagement affects tactile processing and attention. ► Tactile inhibition of return was abolished when engaging in a visual task. ► Visual engagement led to crossmodal attenuation of somatosensory processing. ► ERP correlates of exogenous attention diminished during visual engagement.
Lost in vision: ERP correlates of exogenous tactile attention when engaging in a visual task

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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 cuedelicited 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.

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 on 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

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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, and 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, Bott, 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). 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, Bolanosani, & Verrillo, 2005; Lloyd, Bolanosani, Howard, & McGlone, 1999; Poliaff, 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 lateralisised 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 fronsoparietal attention network (Nobre, Sebestyen, & Miniussi, 2000; Prahmsra, 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 (Cherri & 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 N2 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 

\footnote{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 engagement by introducing different weightings for visual and tactile targets (see, for example, Santangelo et al. (2007)).}
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 fingers 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 or 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 with tactile targets (6 cued and 6 uncued; 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 require a response. In the single 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 1700–2300 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 “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 × 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 kΩ, earlobe and ground electrodes below 2 kΩ. 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.

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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 the behavioural performance showed a significant main effect of Task \(F(1,15)=69.21, p<.001, \eta^2_p=.82\) with faster RTs in the single \(\text{(mean 314 ms, 97 standard deviation (SD))}\) compared to the dual task (477 ms, 124 SD). There was also a main effect of Cue \(F(1,15)=20.07, p<.001, \eta^2_p=.57\) and importantly, a significant Task \& Cue interaction \(F(1,15)=14.98, p=.002, \eta^2_p=.50\).

#### 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, N140, and N22 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 \(F(1,15)=10.02, p=.006, \eta^2_p=.40\) 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 significant 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).

### 4. Discussion

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.
\[ \eta^2 = .50, \] and also \( \text{Cue} \times \text{Hemisphere} \) \( F(1,15) = 43.50, \ p < .001, \ \eta^2 = .74 \). Follow-up analysis for each task separately showed a \( \text{Cue} \times \text{Hemisphere} \) interaction in the single \( F(1,15) = 45.09, \ p < .001, \ \eta^2 = .75 \) and dual task \( F(1,15) = 28.69, \ p < .001, \ \eta^2 = .66 \). 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 \( \text{Cue} \times \text{Hemisphere} \) interaction \( F(1,15) = 53.46, \ p < .001, \ \eta^2 = .78 \) representing an LSN in both tasks.

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

### 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 N200) 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.

#### 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 \( F(1,15) = 14.27, \ p < .002, \ \eta^2 = .49 \); as well as a Cue \( \times \) Hemisphere interaction, \( F(1,15) = 29.64, \ p < .001, \ \eta^2 = .66 \). 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.](image-url)

![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.](image-url)
3.2.3. P100. The overall analysis for the P100 showed no interactions including the factors Task and Cue together, however, there was a Cue × Hemisphere interaction \((F(1,15) = 40.87, p < .001, \eta^2_p = .73)\), which was followed up with separate analyses for each hemisphere. Analysis of electrodes ipsilateral to target location showed a significant effect of Cue \((F(1,15) = 8.67, p < .001, \eta^2_p = .37)\). Contralateral hemisphere analysis also demonstrated a significant effect of Cue \((F(1,15) = 7.89, p = .013, \eta^2_p = .35)\) 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 \((F(1,15) = 5.00, p = .041, \eta^2_p = .25)\) and also a Cue × Hemisphere \((F(1,15) = 23.77, p < .001, \eta^2_p = .61)\). Follow-up analyses for each hemisphere showed a significant effect of Cue at ipsilateral electrodes \((F(1,15) = 16.94, p = .001, \eta^2_p = .53)\) 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 \((F(1,15) = 16.19, p = .001, \eta^2_p = .52)\) 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
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. Facilitatory tactile 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
synonymous with reduced exogenous attention effects as mounting evidence now suggests IOR to be at least be 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, Lupianez, & 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 (in press) 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, & Stokic, 1996; Valeriani, Fraioli, Ranghi, & Giaquinto, 2001; Frot, Garcia-Larrea, Guénôt, & Mauguëre, 2001; Mauguëre 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 an 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 (see Fig. 8).
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 ERP responses 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, in press; 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 findings 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; Forss & Joussambi, 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).

Table 2:
Post-target ERP attention effects.

<table>
<thead>
<tr>
<th>Component</th>
<th>N80</th>
<th>P100</th>
<th>N140</th>
<th>Nd1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Single task</td>
<td>p&lt;.013</td>
<td>n.s.</td>
<td>p&lt;.013</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>Dual task</td>
<td>p&lt;.049</td>
<td>n.s.</td>
<td>p&lt;.001</td>
<td>p&lt;.001</td>
</tr>
</tbody>
</table>

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 × 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 × Cue interaction, further separate analysis for each task has been conducted (N80).
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; Mauguie`re et al., 1997; Zhu et al., 2007) while the origin of the N140 is less clear with multiple areas suggested (Garcia-Larrea, Lukaszewicz, & Mauguie`re, 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, & Muller, 2009; Eimer & Forster, 2003a, 2003b; Zopf, Giabbiconi, Gruber, & Muller 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 (IOA) 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.

Q4


