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**Object-based spatial attention in touch: holding the same  
object with both hands delays attentional selection**

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3 Object-based spatial attention in touch: holding the same object with both  
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6 hands delays attentional selection  
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For Review Only

**Abstract**

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Previous research has shown that attention to a specific location on a uniform visual object spreads throughout the entire object. Here we demonstrate that, similar to the visual system, spatial attention in touch can be object-guided. We measured event-related brain potentials (ERPs) to tactile stimuli arising from objects held by observers' hands, when the hands were placed either near each other or far apart, holding two separate objects, or when they were far apart but holding a common object. Observers covertly oriented their attention to the left, the right or both hands, following bilaterally presented tactile cues indicating likely tactile target location(s). Attentional modulations for tactile stimuli at attended compared to unattended locations were present in the time range of early somatosensory components only when the hands were far apart, but not when they were near. This was found to reflect enhanced somatosensory processing at attended locations rather than suppressed processing at unattended locations. Crucially, holding a common object with both hands delayed attentional selection, similar to when the hands were near. This shows that the proprioceptive distance effect on tactile attentional selection arises when distant event locations can be treated as separate and unconnected sources of tactile stimulation, but not when they form part of the same object. These findings suggest that, similar to visual attention, both space- and object-based attentional mechanisms can operate when we select between tactile events on our body surface.

## INTRODUCTION

For vision, it is known that attentional orienting toward locations can be both space- and object-based. Egly, Driver, and Rafal (1994) showed that covert attention can be shifted more rapidly between spatially separate locations when these appear on the same perceptual object than when they appear on different objects (see also Baylis and Driver, 1992; Marino and Scholl, 2005). In other words, space-based attentional costs of responding to visual signals at invalidly cued locations compared to validly cued locations were larger when the target appeared on another object than when it appeared on the same object at an equivalent distance. Egly et al. (1994) suggested that there may be interactions between a space-based system that selectively activates specific locations and an object-based segmentation system that links separate locations on the basis of grouping operations dependent on the current input (see also Humphreys and Riddoch, 1993). It has been proposed by several other researchers that the functional mechanism of this object-based spatial selection is founded on a strengthening of the sensory representation of an entire object because attention spreads throughout the object's boundaries (Vecera and Farah, 1994; Weber, Kramer, and Miller, 1997; Davis, Driver, Pavani, and Shepherd, 2000).

Recently, Martinez, Ramanathan, Foxe, Javitt, and Hillyard (2007) provided electrophysiological evidence that spatial attention directed to one part of a real or illusory object spreads throughout the entire object. Observers were cued to attend to one of four corners of a square, which was either intact or fragmented into four uneven sections (Experiment 1), and either illusory (induced by Kanisza figures) or absent (modified Kanisza figures, Experiment 2). Visual evoked potentials (VEPs) were recorded to brief offsets of either attended or unattended corners. Offsets at

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3 attended locations gave rise to enhanced P1 and N1 components of the VEP compared  
4  
5 to offsets at unattended locations. Importantly, the space-based attentional effects over  
6  
7 N1 (140-180ms post-stimulus onset) were found to be modified by the type of object  
8  
9 configuration: attentional effects in this time range were larger when the square was  
10  
11 fragmented or absent than when it was an intact perceptual object, whether real or  
12  
13 illusory. In other words, these results concur with those of Egly et al. (1994) in  
14  
15 demonstrating that the prioritization of processing at one visual event location over  
16  
17 another is smaller when these locations can be perceptually grouped. Because  
18  
19 grouping effects also occurred for illusory objects, this study confirms that attentional  
20  
21 selection can be truly object-based rather than guided by simple stimulus features  
22  
23 such as parallel lines, as may have occurred in previous studies (see Avrahami, 1999;  
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25 Marino and Scholl, 2005).

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34 To the best of our knowledge, no study has so far investigated whether a  
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36 similar object-based spatial-selection mechanism operates in touch. It is possible that  
37  
38 the spatial selection between tactile events may be modulated by the processing of  
39  
40 non-spatial stimulus attributes, such as object-related information. Several recent  
41  
42 studies have demonstrated that, similar to visual and auditory systems, the  
43  
44 somatosensory system extracts information about the identity and the spatial location  
45  
46 of tactile stimuli in parallel, functionally specialized pathways (so-called *what* and  
47  
48 *where* pathways; De Santis, Spierer, Clarke, and Murray, 2007; Forster and Eimer,  
49  
50 2004; Reed, Klatzky, and Halgren, 2005; Van Boven, Ingeholm, Beauchamp, Bikle,  
51  
52 and Ungerleider, 2005), which may interact with one-another in spatial selective  
53  
54 attention.  
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3 To investigate whether the spread of spatial attention in touch can, like in  
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5 vision, be modulated by object-based information, the present study utilized the so-  
6  
7 called proprioceptive distance effect. Studies of this effect show that attentional  
8  
9 selection between tactile events at different locations on the body is affected by their  
10  
11 separation in external space, as perceived by proprioceptive feedback (“proprioceptive  
12  
13 distance”) (Driver and Grossenbacher, 1996; Eimer, Forster, Fieger, and Harbich,  
14  
15 2004; Lakatos and Shepard, 1997; Moscovitch and Behrmann, 1994; Rinker and  
16  
17 Craig, 1994; Schicke and Röder, in press; Soto-Faraco, Ronald, and Spence, 2004),  
18  
19 analogous to effects of eccentricity on visual spatial attention (e.g. Driver and Baylis,  
20  
21 1991; Eriksen and Eriksen, 1974; Intriligator and Cavanagh, 2001), and related to  
22  
23 proprioceptive modulations of auditory attention (Simon-Dack and Teder-Sälejärvi,  
24  
25 2008). For example, Driver and Grossenbacher (1996) demonstrated that response  
26  
27 times (RTs) to targets on an attended hand were slower when simultaneously  
28  
29 presented distractors on the unattended hand were incongruent, compared to when  
30  
31 they were congruent with the target stimulation. Critically, this interference effect was  
32  
33 less pronounced when the hands were far apart than when they were close together.  
34  
35 Event-related potential (ERP) studies have confirmed that proprioceptive distance  
36  
37 affects early somatosensory processing. Eimer et al. (2004) cued observers to direct  
38  
39 attention to the left or right hand for a tactile discrimination task, and found that  
40  
41 tactile stimuli at attended compared to unattended locations resulted in modulations of  
42  
43 both the somatosensory N140 component and the subsequent negative difference (Nd)  
44  
45 at longer latencies (200-300ms). In the time range of the N140 component, effects of  
46  
47 attention were more pronounced when the hands were far apart than when they were  
48  
49 close together. These findings show that tactile spatial attention to the relevant hand  
50  
51 operates more effectively when the distance of a distracting stimulus is increased in  
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3 external space, even though the somatotopic location of the distractor (irrelevant  
4 hand) remained unchanged, suggesting that tactile spatial selectivity operates in a  
5  
6 spatial frame of reference that is based primarily on external (proprioceptive), rather  
7  
8 than somatotopic, coordinates (see Azañón & Soto-Faraco, 2008, for a recent  
9  
10 discussion on the deployment of both somatotopic and external reference frames in  
11  
12 touch).  
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20 In this present study, we compared the temporal dynamics of attentional  
21  
22 selection for proprioceptively distant tactile events that arise from the same object (a  
23  
24 bar held jointly by both hands) to events that arise from unconnected objects, which  
25  
26 were either separated by the same distance or placed near each other. Tactile  
27  
28 stimulators were embedded in two horizontal wooden bars, which observers held with  
29  
30 their hands. The bars, and observers' hands, were positioned either near each other  
31  
32 (Near condition) or far apart (Far condition), or they were positioned far apart but  
33  
34 solidly linked to each other via a connecting bar that could be attached between them  
35  
36 (Object condition). Tactile stimuli were preceded by tactile directional cues indicating  
37  
38 the to-be-attended hand or directionally neutral cues instructing observers to attend to  
39  
40 both hands. To assess the effects of covert spatial attention on somatosensory  
41  
42 processing, we analyzed somatosensory event-related potentials (ERPs) in response to  
43  
44 tactile stimuli when preceded by valid (indicating the hand that receives the tactile  
45  
46 stimulus), invalid (indicating the opposite hand) and neutral (indicating both hands as  
47  
48 possible stimulus locations) cues. Directionally neutral cues were included in order to  
49  
50 investigate whether tactile attentional selection, and its modulation by proprioceptive  
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52 distance and object conditions, primarily reflect enhancement of processing at  
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54 attended locations, or suppression of processing at unattended locations. Similar to  
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3 other studies of visual (e.g. Luck, Hillyard, Mouloua, Woldorff, Clark, and Hawkins,  
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5 1994), auditory (Schröger and Eimer, 1997) and tactile (Forster and Eimer, 2005)  
6  
7  
8 attention, attentional enhancement was defined as a difference between ERPs to  
9  
10 validly and neutrally cued stimuli in the same direction as that of the general  
11  
12 attentional effect (ERPs to validly vs. invalidly cued stimuli), and attentional  
13  
14 suppression was defined as a difference between ERPs to invalidly and neutrally cued  
15  
16 stimuli in the opposite direction as that of the general attentional effect.  
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19  
20 As our aim was to investigate space- and object-based tactile attentional  
21  
22 selection in the absence of any visuospatial information, we covered the hands and  
23  
24 bars from view. In order to manipulate observers' assumption of tactile events arising  
25  
26 from common or separate objects, we included trials during which observers were  
27  
28 cued to lift the bars off the tabletop a few times throughout each block. The lifting of  
29  
30 the two bars when not connected (Near and Far conditions) would provide sensory  
31  
32 feedback of two separate unimanual actions, while the lifting of the bars when  
33  
34 connected to form a solid object (Object condition) would result in analogous sensory  
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36 feedback from both hands, which was expected to reinforce the assumption that tactile  
37  
38 event locations were unconnected, or arose from a common object, respectively.  
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46 We expected to find an effect of proprioceptive distance on tactile attentional  
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48 selection similar to Eimer et al. (2004). That is, effects of tactile attention (ERPs to  
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50 validly vs. invalidly cued stimuli) were expected to be larger, or arise earlier, in the  
51  
52 Far than in the Near condition, based on the assumption that the gain control over the  
53  
54 flow of information exerted by spatial attention (e.g. Mangun & Hillyard, 1995) is  
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56 greater when the selected location (in our case, the hand) is more spatially separated  
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58 from a distractor location (the other hand). We further hypothesized that, if tactile  
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3 spatial attention is object-guided like visual spatial attention (Egly et al., 1994,  
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5  
6 Martinez et al., 2007), attention should spread throughout the object. That is, effects  
7  
8 of attentional selection between the hands should be smaller, or arise later, when the  
9  
10 hands are touching a common object (Object condition) than when they are separated  
11  
12 by an equivalent distance but are touching two separate objects (Far condition). If,  
13  
14 unlike in vision, attentional selection in touch is not object-guided, and proprioceptive  
15  
16 distance alone determines the extent to which processing at one tactile event location  
17  
18 can be prioritized over those at another, there should be no difference between Far  
19  
20 and Object conditions.  
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## 26 27 **METHODS**

### 28 29 **Participants**

30  
31 Sixteen paid volunteers participated in the experiment. Four participants were  
32  
33 excluded due to poor eye fixation control (see below), so that twelve participants  
34  
35 (eight males, aged 20-37 years, mean 26.5 years) remained in the sample. All  
36  
37 participants were right-handed and had normal or corrected-to-normal vision by self-  
38  
39 report.  
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### 43 44 **Stimuli and Apparatus**

45  
46 Participants sat in a dimly lit experimental chamber, fixating on a small green  
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48 LED about 65 cm in front of the body midline. A tabletop microphone was placed in  
49  
50 front of them to record vocal response latencies. A video camera monitored  
51  
52 participants throughout the experimental session. Participants were holding on to bars  
53  
54 with their left and right hands, and with their left and right index and middle fingers  
55  
56 placed onto tactile stimulators which were embedded in the bars. The bars were  
57  
58 constructed so that they were about 6cm above the tabletop, affording a grip-like hand  
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3 position (see Fig. 1). In different conditions, the bars, and therefore the hands, were  
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5 either placed close together (Near condition), far apart (Far condition), or far apart but  
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7 solidly connected to one another through an additional bar between them (Object  
8  
9 condition)<sup>1</sup>. In the Near condition, the bars were placed so that the left and right index  
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11 fingers were 6 cm apart. In the Far and in the Object condition, left and right index  
12  
13 fingers were 56 cm apart. The bars were held at a distance of about 30 to 45 cm from  
14  
15 the body, depending on what distance felt comfortable for each participant while  
16  
17 maintaining their grip. The bars and participants' hands were covered from view by a  
18  
19 black wooden board, which was placed about 30 cm above the tabletop.  
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27 Figure 1 about here  
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31  
32 Tactile stimuli were presented using four 12-volt solenoids, driving a metal rod  
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34 with a blunt conical tip to the fingertips of the left and right index and middle fingers,  
35  
36 making contact with the finger whenever a current was passed through the solenoid.  
37  
38 White noise (65 dB SPL, measured from the position of the participants' head) was  
39  
40 continuously present to mask any sounds made by the tactile stimulators.  
41  
42

43  
44 Tactile attentional cues were presented to the left and the right middle finger  
45  
46 simultaneously, and consisted of simple taps or vibrations. Vibrations, generated by  
47  
48 presenting a sequence of rapidly delivered brief pulses, were used as directional cues,  
49  
50 indicating the left or right hand as the likely target location. One of the two target  
51  
52 locations was associated with a 'flutter' vibration, and the other with a 'continuous'  
53  
54 vibration. For 'flutter' vibrations, the stimulus onset asynchrony (SOA) between  
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57  
58  
59 <sup>1</sup> To ensure that tactile stimulation at one end of the bar did not travel along the object and contaminate  
60 ERPs to stimuli at the other end, we recorded EEG during the presentation of stimuli at the side held by one hand, at the other side (not held), and when no stimuli were presented, and found that no somatosensory ERPs were evoked from stimulation at the other side of the object, similar to when no stimuli were presented.

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3 successive 6 ms pulses was 54 ms, corresponding to a rectangular stimulation frequency  
4  
5 of about 16.7 Hz. For 'continuous' vibrations, the SOA between successive 2 ms pulses  
6  
7 was 18 ms, corresponding to a frequency of 50 Hz. Simple taps, where the rod of the  
8  
9 solenoid contacted both middle fingers continuously for 300 ms, were used as  
10  
11 directionally neutral cues (indicating both target locations). As the duration of each  
12  
13 tactile cue (measured as the interval between the onset of the first pulse and the offset of  
14  
15 the last pulse) would be different for the different types of cue, a 2 ms pulse was  
16  
17 presented at 300 ms following cue onset, rendering the cue duration 302 ms for simple  
18  
19 taps, 'flutter' vibrations, and 'continuous' vibrations alike. There was a fourth type of  
20  
21 cue, indicating that participants should briefly lift up the bars, which consisted of a  
22  
23 'flutter' vibration at all four fingers. Left and right middle fingers were contacted for 30  
24  
25 ms, followed by a 30 ms contact of both left and right index fingers, repeated 5 times,  
26  
27 such that the total duration of the Lift bar(s) cue was 300 ms. Tactile target and non-  
28  
29 target stimuli, which were presented unilaterally to the left or the right index finger,  
30  
31 consisted of single and double taps. For single taps (non-targets), the rod of the solenoid  
32  
33 contacted the finger continuously for 200 ms. For double taps (targets), continuous  
34  
35 contact was made for two periods of 85 ms, separated by a 30 ms pause, resulting in a  
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37 total stimulus duration of 200 ms.  
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## 46 Procedure

47  
48 The experiment consisted of twelve blocks, each consisting of 144 trials (see  
49  
50 Table 1 for trial types and their frequency). Four blocks of each condition (Near, Far,  
51  
52 Object) were presented successively, with the order counterbalanced across participants.  
53  
54 Each trial started with a 302 ms presentation of the directional or non-directional tactile  
55  
56 cue, or a 300ms presentation of the Lift bar(s) cue. 1000 ms after cue offset, a tactile  
57  
58 target or non-target stimulus was presented to the left or right index finger. Lift bar(s)  
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3 cues were never followed by a tactile stimulus, but by a 2000 ms pause before the onset  
4  
5 of the next cue. Otherwise, the inter-trial interval was 1000 ms. Participants were  
6  
7 instructed to keep their eyes open and to fixate their gaze straight ahead on the green  
8  
9 LED, to respond vocally (“pa”) whenever a target stimulus (a double tap) was detected  
10  
11 at the attended location, and to ignore all tactile non-target stimuli (single taps) as well as  
12  
13 target stimuli at the unattended location. Tactile cues indicated the most likely location  
14  
15 for a target to occur. For six participants, a ‘flutter’ vibration was associated with the left  
16  
17 hand and a ‘continuous’ vibration was associated with the right hand, and for the other  
18  
19 six participants, cues and target locations were associated in the reverse manner. Neutral  
20  
21 cues (simple taps) were associated with both target locations for all participants. Since  
22  
23 participants responded to targets at attended locations only on validly and neutrally cued  
24  
25 trials, behavioral performance was not analyzed further.  
26  
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32 -----  
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34 Table 1 about here  
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### 39 **EEG Recording**

40  
41 EEG was recorded with Ag-AgCl electrodes and online linked-earlobe  
42  
43 reference from Fp1, Fp2, F3, Fz, F4, FC5, FC1, FCz, FC2, FC6, T7, C3, Cz, C4, T8,  
44  
45 CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, O1 and O2 (subset of the international 10-10  
46  
47 system). Horizontal EOG was recorded bipolarly from the outer canthi of both eyes.  
48  
49 To encourage participants to lift the bars quickly, and to enable monitoring their  
50  
51 performance during Lift bar(s) trials, additional electrodes were placed on the deltoid  
52  
53 muscles of the left and right arms, although muscle EMG was recorded from the right  
54  
55 arm only. Electrode impedance was kept below 2 k $\Omega$  for reference and ground  
56  
57 electrodes, and below 5 k $\Omega$  for all other electrodes, and the impedances of the earlobe  
58  
59  
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3 electrodes were kept as equal as possible. A BrainAmps amplifier and Brain Vision  
4 Recorder (version 1.02) and Analyzer (version 1.05) software (BrainProducts GmbH)  
5  
6 were used for recording and offline analysis of the EEG data. Amplifier band-pass  
7  
8 was 0.01 – 100 Hz, and digitisation rate was 500 Hz. EEG was filtered off-line with a  
9  
10 digital low pass filter of 40 Hz. EEG and HEOG were epoched in separate offline  
11  
12 analysis and were extracted for a period from 100 ms before to 400 ms after the onset  
13  
14 of the tactile stimulus. To check for eye movements in the interval between cue and  
15  
16 tactile stimulus onsets, epochs were also extracted for the 1000 ms period between the  
17  
18 onset of the cue and the onset of the tactile stimuli. Averaged HEOG waveforms  
19  
20 obtained in this interval were scored for systematic deviations of eye position,  
21  
22 indicating a tendency to move the eyes towards the cued side. Four participants were  
23  
24 disqualified due to residual HEOG deflections exceeding  $\pm 4 \mu\text{V}$  in the cue-tactile  
25  
26 stimulus interval. Analyses were only conducted for ERPs obtained in response to  
27  
28 tactile non-target stimuli. Trials with horizontal eye movements (HEOG exceeding  $\pm$   
29  
30  $40 \mu\text{V}$  relative to baseline), eye blinks or other artefacts (a voltage exceeding  $\pm 70 \mu\text{V}$   
31  
32 at any electrode relative to baseline) measured in the interval starting 100 ms before  
33  
34 cue onset and ending 400 ms after the onset of the non-target stimulus, were excluded  
35  
36 from analysis.  
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### 45 **ERP Analysis**

46  
47 ERPs to tactile non-targets were averaged relative to a 100 ms pre-stimulus  
48  
49 baseline for all combinations of cue type (valid vs. invalid vs. neutral), stimulated  
50  
51 hand (left vs. right), and hand condition (Near vs. Far vs. Object). ERP mean  
52  
53 amplitudes were computed within successive measurement windows centred on the  
54  
55 latencies of early somatosensory ERP components P100 and N140 (96-150 ms post-  
56  
57 stimulus). To investigate longer-latency effects of attention, mean amplitudes were  
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59  
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3 also computed between 170 ms and 300 ms post-stimulus. For each of these two time  
4  
5 windows, statistical analyses of ERP mean amplitudes were conducted initially to  
6  
7 compare the effect of hand condition (Near vs. Far vs. Object) on overall effects of  
8  
9 attention (validly vs. invalidly cued trials)<sup>2</sup>. These analyses were conducted separately  
10  
11 for lateral recording sites F3/4, F7/8, FC1/2, FC5/6, C3/4, CP1/2, CP5/6, P3/4, P7/8,  
12  
13 and O1/2, and for midline electrodes Fz, FCz, Cz, and Pz. Lateral recording sites were  
14  
15 grouped into four quadrants of five electrodes each, as defined by lateral and  
16  
17 anteroposterior axes (anterior-ipsilateral: F3/4i, F7/8i, FC1/2i, FC5/6i, C3/4i; anterior-  
18  
19 contralateral: F3/4c, F7/8c, FC1/2c, FC5/6c, C3/4c; posterior-ipsilateral: CP1/2i,  
20  
21 CP5/6i, P3/4i, P7/8i, O1/2i; posterior-contralateral: CP1/2c, CP5/6c, P3/4c, P7/8c,  
22  
23 O1/2c). For lateral recording sites, repeated measures ANOVAs were conducted for  
24  
25 the within-subject factors cue type (valid vs. invalid), hand condition (Near vs. Far vs.  
26  
27 Object), laterality (contralateral vs. ipsilateral electrode sites), anterior-posterior  
28  
29 location (anterior vs. posterior electrode sites) and electrode site (see above). For  
30  
31 recording sites along the midline, repeated measures ANOVAs were conducted for  
32  
33 the within-subject factors cue type (valid vs. invalid), hand condition (Near vs. Far vs.  
34  
35 Object) and electrode (Fz vs. FCz vs. Cz vs. Pz). Follow-up analyses were conducted  
36  
37 for each combination of the three hand conditions (Near vs. Far, Far vs. Object, and  
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39 Near vs. Object) in each time window and for the subsets of electrodes where overall  
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41 effects of hand condition on attention were found. In these analyses, further follow-up  
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43 analyses were conducted to identify effects of attention in each of the three hand  
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55 <sup>2</sup> We also analyzed earlier components P45 (30-60ms) and N80 (60-90ms), but these analyses are not  
56 reported since there were no effects of or interactions with attention for lateral or midline electrodes  
57 (all:  $F(1,11) \leq 2.2$ ,  $p \geq .136$ ), except the following. Over P45, there was a very marginal interaction  
58 between attention, hand condition and laterality ( $F(1,11)=2.7$ ,  $p=.095$ ), but pairwise comparisons  
59 showed no attentional effects at any levels of hand condition and laterality ( $p \geq .208$ ). Over N80, there  
60 was an interaction between attention, laterality and anterior-posterior location ( $F(1,11)=7.4$ ,  $p=.020$ ),  
but pairwise comparisons showed no attentional effects at any levels of laterality and anterior-posterior  
location ( $p \geq .125$ ).

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3 conditions separately, for each time window and for the subsets of electrodes where  
4 effects of hand condition on attention were found. To test whether attentional effects  
5 were based on enhancement or suppression of processing at attended or unattended  
6 locations, respectively, separate analyses were conducted comparing conditions of cue  
7 type (valid vs. neutral, and neutral vs. invalid) for each hand condition, time window,  
8 and for the subsets of electrodes where overall effects of attention were found. When  
9 appropriate, Greenhouse-Geisser adjustments to the degrees of freedom were applied.  
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## 20 21 22 **RESULTS**

23  
24 Figure 2 shows somatosensory ERPs in response to tactile non-target stimuli  
25 at a subset of electrodes ipsilateral and contralateral to the stimulated hand, as well as  
26 at midline electrode Cz. ERPs are presented separately for stimuli at validly (black  
27 lines), invalidly (light grey lines) and at neutrally cued locations (dark grey lines),  
28 when the hands were positioned near (Figure 2A), far (Figure 2B), and far but  
29 connected through an object (Figure 2C). Figure 3 shows ERPs to stimuli at validly  
30 and invalidly cued locations for one representative electrode over somatosensory  
31 cortex contralateral to the stimulated hand (C3/4c, panel A), and voltage difference  
32 maps (activations in response to validly cued vs. invalidly cued stimuli) for the time  
33 range in which attentional effects differed between hand conditions (panel B). ERPs  
34 and voltage difference maps are shown for each of the three hand conditions (Near:  
35 top panel, Far: middle panel, Object: bottom panel).  
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55 Figure 2(A,B,C) about here  
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3 In the *Near* condition (Fig. 2A, Fig. 3 top panel), modulations of attention  
4 were only present at later processing stages, in the time range following the N140  
5 component, where they appeared as an Nd between tactile stimuli at validly and  
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8 component, where they appeared as an Nd between tactile stimuli at validly and  
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11 invalidly cued locations. In the *Far* condition (Fig. 2B, Fig. 3 middle panel),  
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13 attentional modulations were present much earlier. ERPs in response to tactile stimuli  
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15 at validly cued locations showed an enhanced positivity compared to stimulation at  
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18 invalidly cued locations, which started in the time range of the P100 component and  
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20  
21 extended into the time range of the N140 component. These attentional modulations  
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23 appeared to be far more prominent over anterior than over posterior electrode sites.  
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25 Similar to the *Near* condition, there was also an Nd effect of attention. In contrast to  
26  
27 the early somatosensory modulations present in the *Far* condition, when the hands  
28  
29 were far apart but connected by an *Object* (Fig. 2C, Fig. 3 bottom panel), effects of  
30  
31 attention appeared to be only present as an Nd effect, but not at earlier stages.  
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34 These informal observations were tested with an overall ANOVA  
35  
36 investigating effects of hand condition (*Near* vs. *Far* vs. *Object*) on attention (valid vs.  
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38 invalid) in the early and the late time window.  
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43 Figure 3 about here  
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48 *Effects of hand condition on early attentional selection.* For the time window  
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50 of the earlier components (96-150 ms), effects of attention differed as a function of  
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52 hand condition specifically over anterior electrodes for lateral electrode sites (hand  
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54 condition \* cue type \* anterior-posterior location:  $F(1,11)=3.8$ ,  $p=.040$ ; hand  
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56 condition \* cue type \* anterior-posterior location \* electrode site:  $F(1,11)=3.3$ ,  
57  
58  $p=.016$ ), as well as for midline sites (hand condition \* cue type \* electrode site:  
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3 F(1,11)=4.6,  $p=.013$ ). For lateral electrode sites, there were no effects of laterality  
4  
5 (hand condition \* cue type \* laterality:  $F(1,11)<1$ ,  $p=.975$ ; hand condition \* cue type  
6  
7 \* anterior-posterior location \* laterality:  $F(1,11)<1$ ,  $p=.618$ ). Simple effects analyses  
8  
9 revealed that there were significant effects of attention in the Far condition over  
10  
11 lateral anterior ( $p=.007$ ), but not over posterior sites ( $p=.317$ ), and not over either  
12  
13 lateral anterior or posterior sites in both Near or Object conditions ( $p\geq.394$ ). Effects of  
14  
15 attention in the Far condition were present for all lateral anterior electrodes ( $p\leq.029$ )  
16  
17 as well as for anterior midline electrodes Fz, FCz and Cz ( $p\leq.038$ ), and marginal or  
18  
19 absent for lateral posterior electrodes ( $p\geq.075$ ) as well as for posterior midline  
20  
21 electrode Pz ( $p=.431$ ). In both Near and Object conditions, effects of attention were  
22  
23 absent for all lateral ( $p\geq.190$ ) and midline ( $p\geq.318$ ) electrodes.  
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30 Therefore, we separately compared the effects of hand condition on attentional  
31  
32 selection for lateral anterior electrode sites and anterior midline sites Fz, FCz and Cz  
33  
34 for each combination of the three hand conditions (Near vs. Far, Far vs. Object, and  
35  
36 Near vs. Object). Effects of attention were larger in the Far compared to the Near  
37  
38 condition (hand condition \* cue type: all  $F(1,11)\geq 5.7$ ,  $p\leq.036$  for lateral and midline  
39  
40 electrode sites), irrespective of laterality (hand condition \* cue type \* laterality:  
41  
42  $F(1,11)<1$ ,  $p=.687$  for lateral electrode sites). Effects of attention were marginally  
43  
44 larger in the Far compared to the Object condition for lateral electrode sites (hand  
45  
46 condition \* cue type:  $F(1,11)=4.1$ ,  $p=.067$ ), irrespective of laterality (hand condition \*  
47  
48 cue type \* laterality:  $F(1,11)<1$ ,  $p=.669$  for lateral electrode sites). For midline sites,  
49  
50 effects of attention were larger in the Far compared to the Object condition as a  
51  
52 function of electrode sites (hand condition \* cue type \* electrode site:  $F(1,11)=5.7$ ,  
53  
54  $p=.029$ ). Separate analyses for each electrode site showed that effects of attention  
55  
56 were larger in the Far compared to the Object condition for electrode Fz (hand  
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3 condition \* cue type:  $F(1,11)=8.1$ ,  $p=.016$ ), but not for electrodes FCz or Cz (hand  
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5 condition \* cue type:  $F(1,11)<2.6$ ,  $p\geq.136$ ). Importantly, effects of attention did not  
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7 differ between Near and Object conditions (hand condition \* cue type:  $F(1,11)<1$ ,  
8  
9  $p\geq.591$  for lateral and midline electrode sites), irrespective of laterality (hand  
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11 condition \* cue type \* laterality:  $F(1,11)<1$ ,  $p=.952$  for lateral electrode sites).  
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15 For the same set of electrodes, analyses of attentional effects were also  
16  
17 conducted for each of the three hand conditions separately. For the Far condition,  
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19 effects of attention (cue type: all  $F(1,11)\geq 10.9$ ,  $p\leq.007$  for lateral and midline  
20  
21 electrodes) differed as a function of electrode site for lateral electrodes (cue type \*  
22  
23 electrode site:  $F(1,11)=3.9$ ,  $p=.036$ ), irrespective of laterality (cue type \* laterality \*  
24  
25 electrode site:  $F(1,11)=1.6$ ,  $p=.212$ ), and differed marginally as a function of electrode  
26  
27 site for midline electrodes (cue type \* electrode site:  $F(1,11)=4.4$ ,  $p=.053$ ). Separate  
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29 analyses for each electrode site showed that effects of attention were present for all  
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31 lateral electrodes (cue type: all  $F(1,11)\geq 6.3$ ,  $p\leq.029$ ), as well as for all midline  
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33 electrodes (cue type: all  $F(1,11)\geq 5.6$ ,  $p\leq.038$ ), but they were largest over frontal  
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35 electrodes F3/4 and Fz (cue type: all  $F(1,11)\geq 14.4$ ,  $p\leq.003$ ), followed by frontocentral  
36  
37 electrodes FC1/2 and FCz (cue type: all  $F(1,11)\geq 10.5$ ,  $p\leq.008$ ), and were smallest for  
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39 central electrodes C3/4 and Cz (cue type: all  $F(1,11)\geq 14.4$ ,  $p\leq.038$ ) and the more  
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41 temporally situated frontal and frontocentral electrodes F7/8 and FC5/6 (cue type: all  
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43  $F(1,11)\geq 14.4$ ,  $p\leq.029$ ).  
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50 For the Near condition, there were no effects of attention (cue type: all  
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52  $F(1,11)<1$ ,  $p\geq.831$  for lateral and midline electrodes), independently of electrode site  
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54 (cue type \* electrode site: all  $F(1,11)<1$ ,  $p\geq.663$  for lateral and midline electrodes).  
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56 For lateral electrode sites, there was a marginally significant interaction between  
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58 attention and laterality (cue type \* laterality:  $F(1,11)=4.1$ ,  $p=.067$ ), but simple effects  
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3 indicated that there were no effects of attention at either ipsi- or contralateral sites ( $p$   
4  $\geq .625$ ).  
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8 For the Object condition, there were also no effects of attention (cue type: all  
9  $F(1,11) < 1$ ,  $p \geq .394$  for lateral and midline electrodes), independently of electrode site  
10 cue type \* electrode site: all  $F(1,11) \leq 1.7$ ,  $p \geq .214$  for lateral and midline electrodes)  
11 or laterality (cue type \* laterality:  $F(1,11) = 2.1$ ,  $p = .179$  for lateral electrode sites).  
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20 *Effects of hand condition on late attentional selection.* For the time window of  
21 the Nd (170-300 ms), effects of attention (cue type: all  $F(1,11) \geq 23.3$ ,  $p \leq .001$  for  
22 lateral and midline electrode sites) did not differ as a function of hand condition (hand  
23 condition \* cue type: all  $F(1,11) < 1$ ,  $p \geq .540$  for lateral and midline electrode sites).  
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Attentional effects were larger for ipsilateral than contralateral electrode sites (cue  
type \* laterality:  $F(1,11) = 7.9$ ,  $p = .017$ ; cue type \* laterality \* electrode site:  
 $F(1,11) = 6.8$ ,  $p = .009$ ), especially over anterior electrode sites (cue type \* laterality \*  
anterior-posterior location:  $F(1,11) = 38.7$ ,  $p < .001$ ; cue type \* laterality \* anterior-  
posterior location \* electrode site:  $F(1,11) = 13.5$ ,  $p < .001$ ). Attentional effects also  
differed as a function of electrode for midline sites (cue type \* electrode:  $F(1,11) = 5.9$ ,  
 $p = .024$ ). Simple effects analyses indicated that, across all hand conditions, attentional  
effects were marginal for anterior contralateral electrode F7/8c ( $p = .051$ ) but otherwise  
present for all electrodes in all lateral quadrants ( $p \leq .008$ ), as well as for all midline  
electrodes ( $p \leq .005$ ), but they were largest over frontal electrodes F3/4i and Fz,  
frontocentral electrodes FC1/2i, FC1/2c and FCz, central electrodes C3/4i and Cz, and  
centroparietal electrodes CP1/2i and CP1/2c (all  $p \leq .005$ ).

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*Effects of attentional enhancement and suppression.* In this study, we also included trials where attention was cued to both hands, and compared somatosensory ERPs evoked by stimuli in these trials (neutrally cued stimuli) with those evoked in trials where only one hand was selectively attended in order to assess the relative contributions of attentional enhancement (validly vs. neutrally cued stimuli) and suppression (invalidly vs. neutrally cued stimuli) to overall attentional effects (validly vs. invalidly cued stimuli). Somatosensory ERPs in response to tactile non-target stimuli at validly, invalidly, and neutrally cued locations are shown in Figure 2 separately for the three hand conditions. The earliest attentional modulations were evident for the time range of the P100 and N140 components in the Far condition (Figure 2B). These early modulations appeared to reflect attentional enhancement rather than suppression, that is, ERPs in response to stimuli at validly cued locations differed, not only from those to stimuli at invalidly cued locations, but also from those at neutrally cued locations over most electrode sites, while ERPs to neutrally and invalidly cued stimuli did not differ. In addition to these early modulations, attentional modulations were also present as Nd effects in all three hand conditions. In contrast to earlier attentional modulations, Nd effects on somatosensory processing appeared to reflect primarily attentional suppression, that is, ERPs to stimuli at invalidly cued locations differed, not only from those to stimuli at validly cued locations, but also from those at neutrally cued locations, while ERPs to validly and neutrally cued stimuli did not differ.

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To formally test these observations, ANOVAs were carried out for anterior lateral and midline electrode sites for the time window of earlier attentional effects in the Far condition, and for all electrode sites for the time window of the Nd for all three hand conditions. The contribution of *attentional enhancement* to earlier

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attentional effects were shown by differences between waveforms to validly and neutrally cued stimuli (cue type: all  $F(1,11) \geq 8.5$ ,  $p \leq .014$  for lateral and midline electrode sites) in the absence of differences between waveforms to neutrally and invalidly cued stimuli (cue type: all  $F(1,11) < 1$ ,  $p \geq .703$  for lateral and midline electrode sites). Similar to the overall attentional effect (validly vs. invalidly cued stimuli), attentional enhancement for validly compared to neutrally cued stimuli was present irrespective of laterality (cue type \* laterality:  $F(1,11) = 1.5$ ,  $p = .243$  for lateral electrode sites). Enhancement did not differ across electrode site (cue type \* electrode site: all  $F(1,11) \leq 2.6$ ,  $p \geq .128$  for lateral and midline electrode sites).

For the Nd, effects of *attentional suppression* were shown by differences between waveforms to neutrally and invalidly cued stimuli (cue type: all  $F(1,11) \geq 29.0$ ,  $p < .001$  for lateral and midline electrode sites) in the absence of differences between waveforms to validly and neutrally cued stimuli (cue type: all  $F(1,11) \leq 1.3$ ,  $p \geq .273$  for lateral and midline electrode sites). Similar to the overall attentional effect (validly vs. invalidly cued stimuli), attentional suppression for invalidly compared to neutrally cued stimuli was larger for ipsilateral than contralateral electrode sites specifically over anterior electrode sites (cue type \* laterality \* anterior-posterior location:  $F(1,11) = 5.4$ ,  $p = .040$ ), although it was not larger for ipsilateral sites overall (cue type \* laterality:  $F(1,11) = 1.5$ ,  $p = .248$ ).

Attentional suppression also differed as a function of electrode (cue type \* electrode: all  $F(1,11) \geq 4.9$ ,  $p \leq .031$  for lateral and midline sites). Although suppression was present for all lateral and midline electrodes ( $p \leq .003$ ), it was largest for frontocentral electrodes FC1/2i, FC1/2c and FCz, central electrodes C3/4i, C3/4c and Cz, and centroparietal electrodes CP1/2i and CP1/2c (all  $p < .001$ ).

## DISCUSSION

To investigate whether tactile spatial attention can be object based, analogous to visual spatial attention (Egly et al., 1994; Martinez et al., 2007), we recorded ERP correlates of the proprioceptive distance effect on tactile spatial attention (Driver and Grossenbacher, 1996; Eimer et al., 2004; Soto-Faraco et al., 2004), and tested whether spatial attentional selection between proprioceptively distant hands is attenuated, or arises later, when the hands are connected by a jointly held object. Based on Eimer et al.'s (2004) study, which showed that ERP correlates of tactile spatial attention are modulated by the proprioceptive distance of the site of tactile stimulation (hands), we devised a task in which participants were holding either one or two objects while their hands were positioned either near or far apart. We compared attentional selection for tactile events on the hands in three different conditions: when tactile stimulation arose from two separate objects that observers held in their hands, when the hands were placed either near together or far apart, and when tactile stimulation arose from a common object held by both hands that were placed far apart. We induced the perception of whether or not tactile event locations were separate or connected by occasionally cueing observers to lift the object(s) they were holding as part of each experimental block. In order to investigate tactile attentional selection in the absence of any engagement of visuospatial orienting mechanisms we cued observers' attention tactually, rather than visually as done in most previous studies of tactile spatial attention. In addition, we included directionally neutral cues in order to explore the relative contributions of enhancement at attended locations and suppression at unattended locations to effects of tactile attentional selection.

Previous studies have shown that the representation of hand positions in external space profoundly affects tactile attentional selection (Driver and

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Grossenbacher, 1996; Soto-Faraco et al., 2004). In line with equivalent effects on early somatosensory processing (Eimer et al., 2004), the present study shows that proprioceptive information about hand location modulates the mechanisms underlying tactile spatial attention. For this modulation to occur, integration between tactile and proprioceptive information must have taken place prior to the operation of attentional selection. We found that effects of attentional selection arose earlier (96-150 ms post-stimulus) when the hands were placed far apart than when they were near each other (170-300 ms post-stimulus). These earlier attentional effects were present over anterior electrodes as an enhanced positivity for attended compared to unattended stimuli. Interestingly, effects of attentional selection were also delayed (170-300 ms post-stimulus) when hands were placed far apart, but were holding the same object. In fact, evoked responses in the Object condition did not differ from those observed when the hands were placed near each other. These findings show for the first time that object-based information about tactile events on the hands affects the temporal dynamics of tactile attentional selection, suggesting that tactile spatial attention, analogous to visual attention, can be both space- and object-based.

Our findings also show that early effects (96-150 ms post-stimulus) of proprioceptive distance on attentional selection (Far condition) consist primarily of an enhancement of processing for stimuli at the attended hand, rather than of a suppression of processing at the unattended hand. At later processing stages, attentional selection was unaffected by the distance between the hands or whether they were holding an object; all three hand conditions showed a similar Nd between tactile stimuli at attended and unattended locations. Attentional effects in the time range of the Nd were found to consist primarily of a suppression of processing for tactile stimuli at invalidly cued locations, compared to those at validly or neutrally



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cued locations, which is in line with previous findings (Forster and Eimer, 2005). In addition, our results suggest that early enhancement of tactile processing at attended locations is only present when tactile stimulus locations originate from separate sources that are sufficiently distant in external space. These findings are in contrast to Driver and Grossenbacher's (1996) suggestion that the more effective attentional selection between proprioceptively distant hands is due to better suppression of events at the unattended, distractor hand, rather than enhancement of events at the attended, target hand. However, in their study participants were presented with tactile stimuli presented simultaneously to both hands. It is conceivable that mechanisms underlying tactile spatial selection may differ with stimulus presentation and task demands. Similar to Forster and Eimer (2005), we have found that attentional enhancement, if present, arises at earlier stages than suppression, which is in contrast to similar studies of visual (Luck et al., 1994) and auditory attention (Schröger and Eimer, 1997), where suppression typically precedes enhancement, and suggests that the component stages of attentional mechanisms in somatosensation differ from those in other modalities. In contrast to our results, however, Forster and Eimer (2005) found that attentional suppression accompanied enhancement at early stages of *visually* cued tactile selection. This difference between the two studies suggests that mechanisms of tactile spatial attention may also be affected by cueing modality.

The most important novel finding of this study is that the proprioceptive distance effect on early tactile attentional selection disappeared when the two hands were separated in external space but connected through a jointly held object. In this condition, effects of attentional selection did not arise until later stages of processing, similar to when the hands were placed near each other. The present findings mirror

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3 analogous findings made for visual spatial attention, and show for the first time that  
4 tactile attention can be both space- and object-based. Behavioral (e.g. Egly et al.,  
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6 1994) and electrophysiological (e.g. Martinez et al., 2007) studies have shown that  
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8 visual spatial attention spreads along object boundaries: effects of attentional selection  
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10 between two equidistant locations are smaller when these locations form part of the  
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12 same perceptual object than when they do not. Similarly, the present study  
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14 demonstrates that effects of attentional selection between the hands are delayed when  
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16 the hands are connected by a jointly held object than when they are separated by the  
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18 same distance but hold two unconnected objects. This suggests that, at these stages,  
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20 no location along a jointly held object receives prioritized processing because, like  
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22 visual attention, tactile attention spreads along object boundaries. In addition to a  
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24 space-based selection system that activates specific tactile event locations over others,  
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26 the tactile modality may have an object-based system that links or segments tactile  
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28 event locations on the basis of grouping operations that can or cannot be performed on  
29  
30 the current input. Previous studies have shown that non-spatial attributes of tactile  
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32 stimuli (e.g. frequency) are selected in parallel with spatial attributes in functionally  
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34 segregated pathways (De Santis et al., 2007; Forster and Eimer, 2004; Reed et al.,  
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36 2005; Van Boven et al., 2005). Our results extend these findings by showing that  
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38 object-related information can modulate the spatial processing of tactile events,  
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40 suggesting that specialized somatosensory *what* and *where* pathways may interact at  
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42 early stages of spatial processing. Our findings also suggest that tactile and visual  
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44 attentional systems may operate in similar ways. Just as the spread of spatial attention  
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46 throughout an entire visual object may be useful for object perception, and indeed  
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48 occurs at the level of regions implicated in object encoding (see Martinez et al.,  
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3 2007), the absence of prioritized processing for locations along an object held by the  
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5 two hands might be useful for purposes such as the bimanual handling of objects.  
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10 In line with previous studies we have shown that tactile attentional selection is  
11 modulated by the proprioceptive distance between stimulus locations (Driver and  
12 Grossenbacher, 1996; Eimer et al., 2004). In addition, our findings suggest that larger,  
13 or earlier, effects of tactile attentional selection with greater separation between the  
14 hands are driven by the system's assumption that proprioceptively distant event  
15 locations can be represented as unconnected sources of information. The  
16 proprioceptive distance effect on tactile attentional selection necessitates that  
17 proprioceptive information about current limb position is integrated with tactile  
18 processing prior to the operations of tactile spatial attention mechanisms. If tactile  
19 attentional selection is object-based, prior knowledge about whether or not tactile  
20 event locations arise from the same or different objects must be integrated with tactile  
21 processing in a similar manner.  
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39 Recently, Helbig and Ernst (2007) showed that prior knowledge about two  
40 events arising from a common source can affect how these events are treated by the  
41 perceptual system. Observers judged the shape of objects they simultaneously touched  
42 and viewed either when they had direct vision of their hand (co-located visual and  
43 haptic information) or when vision of their hand was provided via a mirror (creating a  
44 spatial separation between visual and haptic information). Typically, with greater  
45 spatial separations between the sources of visual and haptic information, their  
46 beneficial effect on one another gradually declines (Gepshtein, Burge, Ernst, and  
47 Banks, 2005), but integration did not differ between viewing conditions in Helbig and  
48 Ernst's study. This suggests that when observers have prior knowledge about object  
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3 identity, that is, when they believe that vision and touch provide redundant  
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5 information about the same object, information from both modalities is integrated,  
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8 overcoming even substantial spatial separations between them. Helbig and Ernst  
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10 (2007) proposed that the system must first decide whether information from different  
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12 sources (different sensory modalities) pertain to the same object or event. If so,  
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14 perceptual integration, which does not typically occur for spatially separate  
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16 multimodal events, can take place in the same way as it would for co-located events.  
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18 In line with this, we suggest that prior knowledge modulated the integration of  
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20 proprioceptive information with tactile input in our study. Because tactile event  
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22 locations could be treated as arising from a common source of stimulation in our  
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24 Object condition, but as arising from separate sources in our Far condition, the  
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26 proprioceptive or spatial distance between them was reflected in attentional  
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28 modulations of early somatosensory processing stages only in the Far condition.  
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36 Our findings suggest that when the hands were proprioceptively distant but  
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38 connected by a common object, attentional selection operated as if the hands were  
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40 near, at least at early stages of processing. The question that arises from these findings  
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42 is whether object-based effects occur despite proprioceptive distance, such that  
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44 distance information is essentially preserved, or whether the nature of the  
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46 proprioceptive information is fundamentally changed through the assumption that  
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48 tactile events on both hands have a common source. That is, object-based effects may  
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50 lead to a representation of the hands as 'near', or as 'connected', thereby essentially  
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52 changing the current body schema with respect to the functional relationship between  
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54 the hands. Future studies should address the question of how the functional  
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3 relationship between the hands is affected, for example by investigating the  
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5 consequences of object-guided selection for the preparation of hand movements.  
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11  
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13  
14 Sciences Research Council (BBSRC).  
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7 **Figure 1.** Experimental setup showing the bars participants held with their left and  
8 right hands in the Far condition. Dotted lines indicate the outline of the connecting bar  
9 used in the Object condition. The inset shows the location of the tactile stimulators  
10 used to present tactile cues (middle fingers), targets and non-targets (index fingers).  
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17 **Figure 2.** Grand-averaged somatosensory ERPs elicited at a subset of sites ipsilateral  
18 (i) and contralateral (c) to the stimulated hand and at midline electrode Cz by tactile  
19 non-target stimuli at validly cued locations (black lines), at invalidly cued locations  
20 (grey lines) and at neutrally cued locations (dashed lines) in the 400 ms interval  
21 following stimulus onset. A: Near. B: Far. C: Object.  
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31 **Figure 3.** A: Enlarged image of ERPs elicited at one representative electrode (C3/4c)  
32 by tactile stimuli at validly cued (black lines) and invalidly cued (grey lines)  
33 locations. The shaded area indicates the 96-150 ms time range. B: Voltage difference  
34 maps (activations elicited by validly cued vs. invalidly cued stimuli) for the 96-150  
35 ms time range in which attentional effects differed between hand conditions. Black  
36 contour lines indicate levels of negative difference, white contour lines indicate levels  
37 of positive difference. Black x indicates the location of C3/4c. Top: Near. Middle:  
38 Far. Bottom: Object.  
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**Table 1.** Trial types defined by conditions of cueing and target/non-target presentation for one block of 144 trials. Left and Right refer to left hand and right hand, respectively.

<i>Cue type (number per block)</i>	<i>Target / Non-target (number per block)</i>
<u>Directional</u>	
Left (47)	Left (12), Right (3) / Left (16), Right (16)
Right (47)	Left (3), Right (12) / Left (16), Right (16)
<u>Non-directional (neutral)</u>	
Left and Right (44-48)*	Left (6-8)*, Right (6-8)* / Left (16), Right (16)
<u>Lift bar(s) (2-6)*</u>	-

\* In all blocks, a total of 138 directional and neutral cueing trials were presented. An additional six trials were drawn from a pool of Lift bar(s) and neutral cue trials, such that at least two, but never more than six, Lift bar(s) trials were selected per block in order to vary the number of such trials across blocks. The remainder (0-4 trials) were trials in which neutral cues were followed by left (0-2) or right (0-2) targets.

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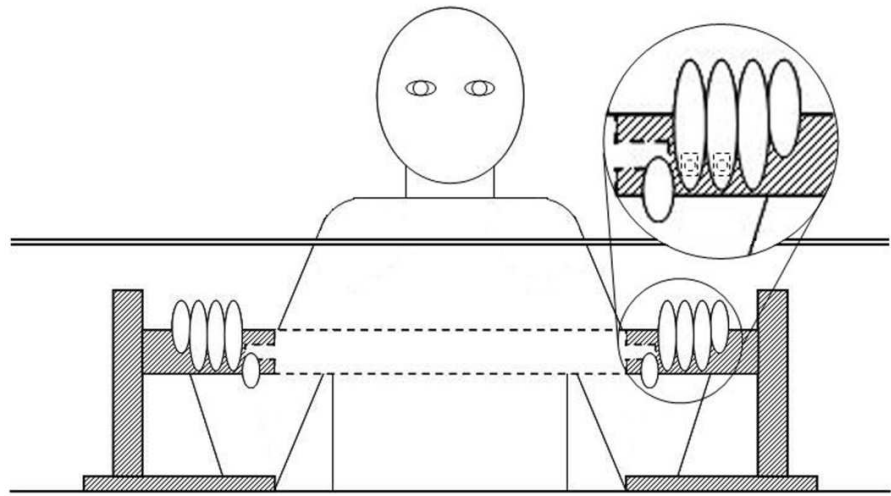


Figure 1. Experimental setup showing the bars participants held with their left and right hands in the Far condition. Dotted lines indicate the outline of the connecting bar used in the Object condition. The inset shows the location of the tactile stimulators used to present tactile cues (middle fingers), targets and non-targets (index fingers).  
49x30mm (600 x 600 DPI)

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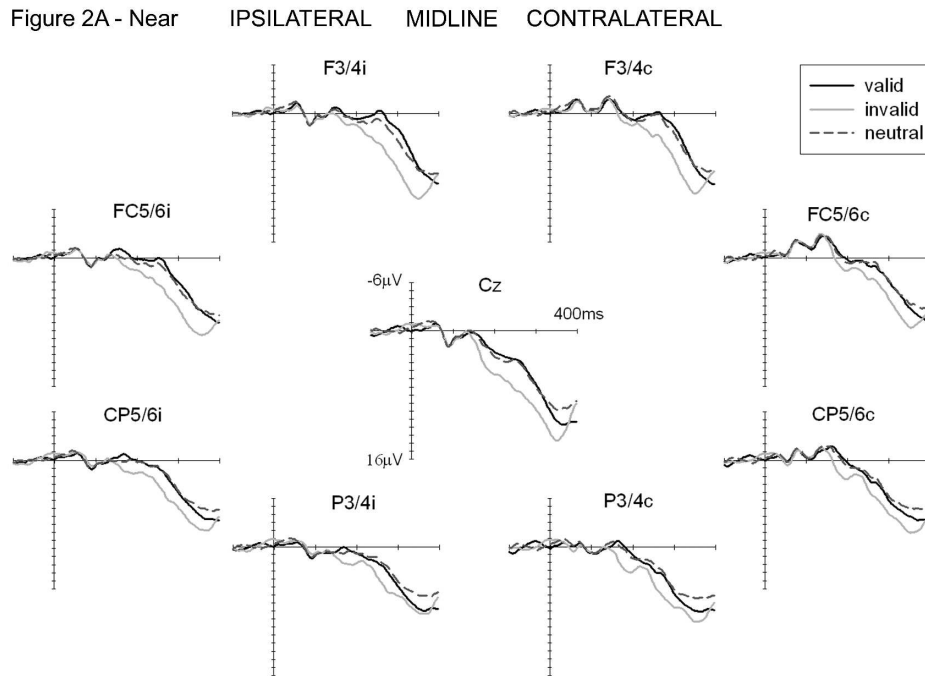


Figure 2. Grand-averaged somatosensory ERPs elicited at a subset of sites ipsilateral (i) and contralateral (c) to the stimulated hand and at midline electrode Cz by tactile non-target stimuli at validly cued locations (black lines), at invalidly cued locations (grey lines) and at neutrally cued locations (dashed lines) in the 400 ms interval following stimulus onset. A: Near. B: Far. C: Object. 277x200mm (500 x 500 DPI)

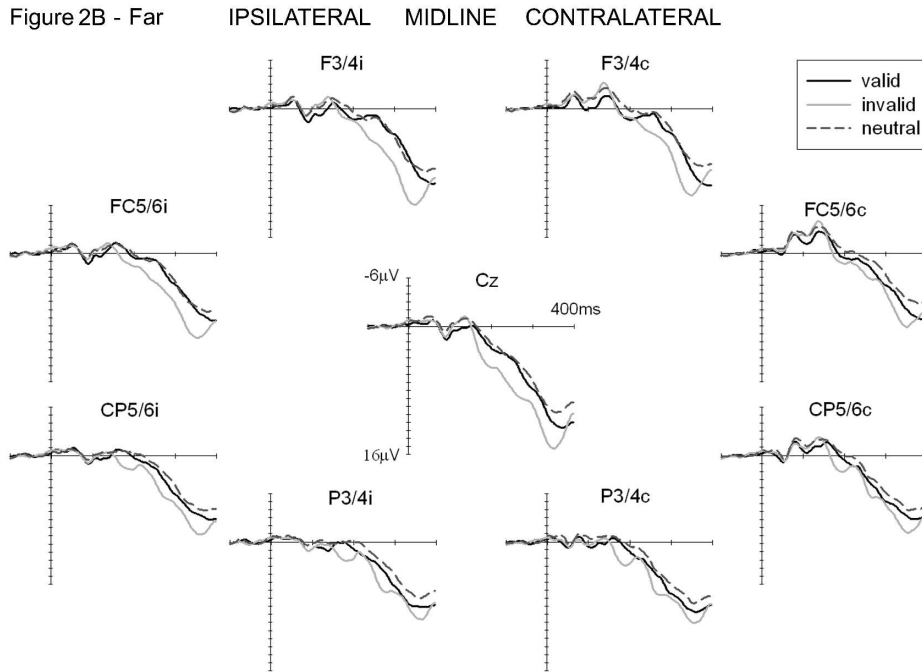


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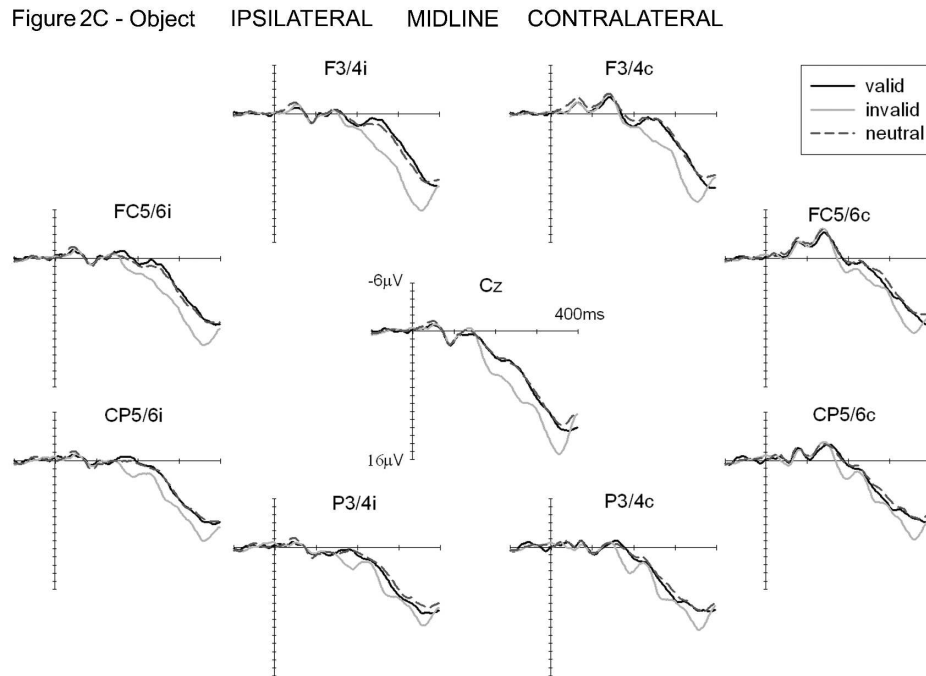


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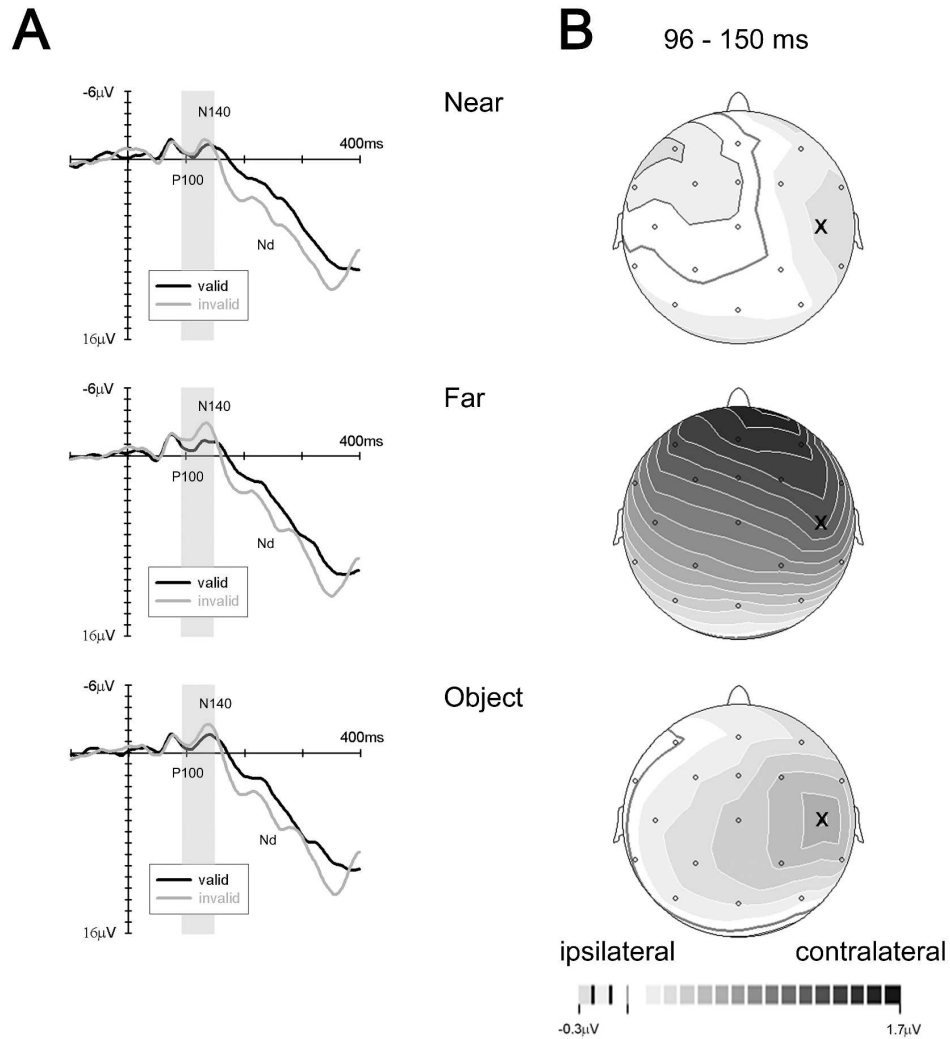


Figure 3. A: Enlarged image of ERPs elicited at one representative electrode (C3/4c) by tactile stimuli at validly cued (black lines) and invalidly cued (grey lines) locations. The shaded area indicates the 96-150 ms time range. B: Voltage difference maps (activations elicited by validly cued vs. invalidly cued stimuli) for the 96-150 ms time range in which attentional effects differed between hand conditions. Black contour lines indicate levels of negative difference, white contour lines indicate levels of positive difference. Black x indicates the location of C3/4c. Top: Near. Middle: Far. Bottom: Object.

178x194mm (500 x 500 DPI)