ORIGINAL ARTICLE

Electrophysiological correlates of attentional selection in tactile search tasks: The impact of singleton distractors on target selection

Carlos I. Mena 🔾 | Kadi Lang | Elena Gherri 🔾

Human Cognitive Neuroscience, Psychology, University of Edinburgh, Edinburgh, United Kingdom

Correspondence
Elena Gherri, Department of Psychology, University of Edinburgh, 7 George Square, Edinburgh EH8 9JZ, United Kingdom.
Email: Elena.Gherri@ed.ac.uk

Abstract

Recent event-related potential (ERP) studies have suggested that the N140cc component reflects target selection mechanisms in tactile search tasks in which the target is presented simultaneously with homogeneous distractors. To investigate if and how the attentional selection of the tactile target is affected by the presence of a singleton distractor, we presented a four-item search array (two stimuli to the middle and index fingers of the left and right hand) which included a singleton distractor in addition to the target and two other homogenous distractors. Participants had to localize the target (top or bottom finger on either hand), while ignoring all distractors. Behavioral results revealed that the target localization was hindered by the presence of the singleton distractor as demonstrated by distractor-presence costs for both speed and accuracy. ERP results confirmed that attention was directed to the singleton distractor when this was the only singleton item in the array as suggested by the presence of a distractor-related N140cc component on distractor only trials. Furthermore, when target and singleton distractor were presented to opposite hands (contralateral distractor trials) the target-related N140cc amplitude was reduced as compared to target only trials, suggesting reduced attentional resources to the target. However, when target and singleton distractor were presented to the same hand (ipsilateral distractor trials), the N140cc amplitude was comparable to that observed on target only trials. These findings suggest that the N140cc reflects the attentional selection of the target side rather than the competition between stimuli presented to the same hand.

KEYWORDS
ERPs, N140cc, singleton distractor, tactile search, tactile selectivity

1 | INTRODUCTION

Although sensory environments are typically characterized by the simultaneous presence of multiple objects, only a small number of these can be fully represented due to the limited capacity of the visual system (e.g., Desimone & Duncan, 1995). Selective attention allows to prioritize the processing of behaviorally relevant objects at the expense of irrelevant ones. Its mechanisms have been extensively investigated in visual search tasks in which participants respond to a task-relevant target presented simultaneously with irrelevant distractors. Importantly, the electrophysiological correlate of covert attentional deployment in visual search tasks has been identified in event-related potential (ERPs) studies (see Eimer, 2014; Luck, 2012; Woodman, 2013 for reviews). ERPs elicited by the search array at occipital electrodes become more negative over the hemisphere contralateral to the target as compared to the ipsilateral one from about 200–300 ms post-array onset (e.g., Eimer, 1996; Luck & Hillyard, 1990, 1994). This lateralized component, labeled N2pc, has been extensively used to investigate the experimental conditions under which selective attention is directed to relevant items in visual search tasks (see Gaspelin & Luck, 2018 for a recent review).

Researchers have just started to investigate whether similar selective attention mechanisms operate in tactile search tasks. In a recent study, participants reported the presence or absence of a target presented among homogenous distractors, high- and low-frequency vibrations, respectively (Forster, Tziraki, & Jones, 2016). On target-present trials, ERPs were more negative over the hemisphere contralateral than ipsilateral to the target side (Forster et al., 2016). This lateralized component, labeled N140cc, was maximal over central electrodes and its onset overlapped with the sensory-specific N140 component. It was suggested that the N140cc is the functional equivalent of the visual N2pc, indexing the deployment of attention during tactile search tasks (c.f. Ambron, Mas-Casadesús, & Gherri, 2018; Katus & Eimer, 2019; Katus, Grubert, & Eimer, 2015).

The aim of this study was to investigate for the first time whether the presence of a singleton distractor affects the selection of the target as indexed by the N140cc. Evidence from visual search tasks suggests that attention can be directed to a singleton distractor when it is particularly salient or shares a relevant feature with the target, as indicated by a distractor-related N2pc observed on target-absent trials (e.g., Burra & Kerzel, 2013; Gaspar, Christie, Prime, Jolicœur, & McDonald, 2016; Hickey, McDonald, & Theeuwes, 2006; Kiss, Driver, & Eimer, 2009; Kiss, Grubert, Petersen, & Eimer, 2012; McDonald, Green, Jannati, & Di Lollo, 2013). Importantly, when both target and distractor are present in the search array, the target-related N2pc is reduced, suggesting degraded target selection processes due to

competitive interactions (ipsilateral distractor, e.g., Hilimire & Corballis, 2014; Hilimire, Mounts, Parks, & Corballis, 2009). Thus, the simultaneous presence of the target and a singleton distractor can shed light on the dynamics of attentional selectivity when there is competition between these stimuli. Previous tactile search studies were unable to address this question because no singleton distractor was present in the search array. In the present study, participants had to identify the target location in a four-item search task in which the target, the singleton distractor and the homogeneous distractors were defined by different vibro-tactile frequencies. We compared trials in which a singleton was present among homogeneous distractors (target only and distractor only trials) with trials in which both singletons were present, either on the same or opposite hands (ipsilateral and contralateral distractor trials, respectively) to investigate whether the singleton distractor engages the attentional mechanisms associated with the N140cc. If attention is directed to the singleton distractor we expect to observe a distractor-related N140cc on distractor only trials. Furthermore, when both singletons are present in the search array, we expect to observe behavioral costs related to the presence of the singleton distractor and modulations of the target-related N140cc.

Two experiments were carried out. In Experiment 1, participants searched for the slowest vibration in the array (target was a 12.5 Hz vibro-tactile frequency, whereas the homogeneous distractors were 100 Hz), whereas in Experiment 2 they searched for the fastest vibration (100 Hz target and 12.5 Hz homogeneous distractors). In both experiments, the singleton distractor was characterized by an intermediate vibration (40 Hz). The manipulation of target (and distractors) frequencies and the comparison between experiments allowed us to determine the impact of stimulus saliency on the attentional processes of target selection and to rule out the possibility that N140cc differences between different types of trials were determined by sensory imbalances in the search array rather than by the mechanisms of tactile selective attention.

2 | METHOD

2.1 | Participants

A total of 43 paid, volunteer adults (20 in Experiment 1, and 23 in Experiment 2) were recruited via word-of-mouth at the University of Edinburgh. All of them had a normal or corrected-to-normal vision and no history of neurological diseases. Due to technical problems with the experimental equipment three participants could not complete the experimental task and were, therefore, excluded from the final sample. A total of 20 participants remained in the sample for both Experiment 1 (13 females and 7 males, $M_{age} = 24.4$, $SD_{age} = 2.1$) and Experiment 2 (11 females and 9 males,

M_{age} = 24.35, SD_{age} = 4.13). These studies were conducted following the Declaration of Helsinki and were approved by the Research Ethics Committee of the Department of Psychology at the University of Edinburgh.

2.2 | Stimuli and apparatus

Participants were seated in a dimly lit, sound-attenuating and electrically shielded booth. They placed their hands on a table with their palms down. The hands were rotated (at an angle of approximately 45°) until index and middle finger of each hand were aligned and parallel to the body midline. The distance between the index fingers of the two hands was 10 cm. Once in the correct position, the hands were covered with a black cardboard, on top of which there was a white pin aligned with the body midline which served as fixation-point. Surgical tape was used to attach four vibro-tactile stimulators to the participants' index and middle fingertips of both hands. These stimulators (Heijo Research Electronics, UK) were 12 V solenoids driving a magnetic rod with a blunt plastic tip which made contact with the skin whenever a current was passed through the solenoid. Two vertically arranged foot-pedals (top and bottom pedals) were positioned under the toes and heel of one of the participants' feet. Participants were asked to keep one foot on these response pedals during the task. White noise (65 dB SPL) was played during the training and throughout the experiment to mask any noise made by the vibro-tactile stimulators.

On each trial, the search array consisted of four vibro-tactile stimuli presented simultaneously. Vibro-tactile stimuli differed with respect to their vibration frequencies (12.5, 40, or 100 Hz). These frequencies consisted of a rapid sequence of pulses during which the rod was in contact with the skin for 5 ms, followed by a variable inter-pulse interval set at 75, 20, and 5 ms for the slow, medium, and fast vibrations, respectively. All stimuli had a total duration of 405 ms. The tactile search array started and ended with all the stimulators touching the skin simultaneously to prevent participants from using the offset of the stimuli to complete the task. In Experiment 1, the target was the slowest vibration (12.5 Hz), the singleton distractor was the middle vibration (40 Hz), and the homogeneous distractors were the fastest vibration (100 Hz). In Experiment 2, the frequencies of target and homogeneous distractors were swapped, so that the target was 100 Hz, the singleton distractor was 40 Hz, and the homogeneous distractors were 12.5 Hz.

There were four different types of trials: target only (one target and three homogeneous distractors), distractor only (one singleton distractor and three homogeneous distractors), ipsilateral distractor (one target, one singleton distractor to the same hand, and two homogeneous distractors to the opposite hand), and contralateral distractor (one target and one homogeneous distractor to one hand, and one singleton distractor and one homogeneous distractor to the opposite hand).

2.3 | Procedure

Each trial started with the presentation of the tactile search array (405-ms) followed by a 1,795-ms interval in which responses were collected. The interstimulus interval between successive search arrays was set at 2,500 ms. At the end of each block, participants were shown a summary of their performance (mean accuracy and RTs).

There were 12 blocks of 80 trials each (960 in total). In each block, the four different types of trials were randomly intermixed. Target and distractor were equally likely to appear in any of the four locations (Figures 3 and 4, small insets). Each type of trial was presented 16 times in each block, except for the contralateral distractor condition which occurred 32 times.[1]

Participants were instructed to respond as fast and accurately as possible to the elevation of the target (top or bottom finger) while ignoring the distractor and the fillers (no response was expected on distractor only trials). They were also asked to keep their eyes on the white fixation pin throughout the blocks.

Before participants started the experiment, they completed a training phase in which they were familiarized with the stimuli and the task. They completed a block of trials in which they had to achieve an overall accuracy level of at least 60% to progress to the experiment. The responding foot was alternated (left or right foot) after each block and the starting foot was counterbalanced across participants.

2.4 | Behavioral analysis

Reaction times (RTs) on all trials were inspected for extreme values using Tukey's fences method (Tukey, 1977), leading to the exclusion of ~2.5% of the trials in each experiment. For the remaining trials, only correct trials RTs were used to compute the means. Because no response was required on distractor only trials, performance on this type of trial was reported, but not included in the statistical analyses. For the remaining types of trials in which participants had to report the location of the target (target only, ipsilateral and contralateral distractor trials), mean accuracy rates, and mean RTs were calculated and submitted to one-way repeated-measures analyses of variances (ANOVAs) with type of trial as independent variable. Following main effects of trial type, contrasts between the three trial types were carried out and their p values were adjusted following the Bonferroni method (three comparisons). These analyses were carried out separately for each experiment.

To determine the impact of stimulus saliency (differences in the task-relevant and irrelevant vibro-tactile frequencies) on the attentional processes of target selection, additional mixed ANOVAs were carried out on the behavioral data of both Experiment 1 and 2 (reported in the General Analyses section). These included Experiment as between-subjects factor and type of trial as a within-subjects factor. Following significant type of trial x experiment interactions, planned contrasts were carried out separately for each type of trial to investigate the presence of reliable differences between experiments.

Finally, to investigate whether the behavioral costs induced by the presence of the distractor differed between experiments, we ran additional two-factor mixed-design ANOVAs in which the dependent variable was the distractor-presence cost (calculated as a performance difference between distractor-absent—i.e., target only—and distractor-present trials—i.e., ipsilateral and contralateral distractor trials—and the independent ones were type of distractor (ipsilateral vs. contralateral)) and experiment (Exp. 1 vs. Exp. 2). Follow-up contrasts for type of distractor across experiments were carried out, and their p values were adjusted using Bonferroni corrections (two comparisons).

2.5 | Electrophysiological recording and analysis

EEG was recorded using a BioSemi ActiveTwo amplifier system from 64 active electrodes (Fpz, Fp1,Fp2, AFz, AF7, AF3, AF4 AF8, Fz, F7, F5, F3, F1, F2, F4, F6, F8, FCz, FT7, FC5, FC3, FC1, FC2, FC4 FC6, FT8, Cz, T7, C5, C3, C1, C2, C4, C6, T8, CPz, TP7, CP5, CP3, CP1, CP2, CP4, CP6, TP8, Pz, P9, P7, P5, P3, P1, P2, P4, P6, P8, P10, POz, PO7, PO3, PO4, PO8, Oz, O1, O2, and Iz) positioned according to the 10–20 system. Two additional electrodes were placed on the earlobes. Horizontal eye movements (HEOG) were recorded from two electrodes placed at the outer canthi of each eye. Vertical eye movements (VEOG) were recorded from two electrodes positioned above and below the right eye. The EEG was sampled at 512 Hz.

EEG data were analyzed using Brain Vision Analyzer (version 2.0.4.368). EEG was digitally re-referenced to the average of the left and right earlobe and was digitally filtered offline (high-pass filter 0.53 Hz, low-pass filter 40 Hz and notch filter 50 Hz). The EEG was epoched into 500 ms intervals starting 100 ms before and ending 400 ms after the search array onset. Trials with eyeblinks (voltage exceeding ±60 µV on the VEOG channel), HEOG (voltage exceeding ±40 µV on the HEOG channel), and other artifacts (voltage exceeding ±80 µV at all other electrode sites) were excluded from further analysis, as were trials with response errors.

In both experiments, ERPs were averaged relative to a 100 ms pre-stimulus baseline separately for all combinations of the different types of trial (target only vs. distractor only vs. ipsilateral distractor vs. contralateral distractor), and stimulated hand (target to the left vs. right hand; or distractor to the left vs. right hand for the distractor only trials). ERP mean amplitude values were computed for each participant at electrodes C5/6 (where the lateralized components of interest were maximal in the present study, and in line with previous studies from our lab, Ambron et al., 2018), within two successive measurement windows 140–240 and 240–340 ms post-stimulus onset (see Ambron et al., 2018; Forster et al., 2016).

To investigate whether the presence and location of a salient distractor modulated the electrophysiological signature of attentional tactile target selection (N140cc), in both experiments repeated-measures ANOVA were conducted for the factors type of trial (target only, distractor only, ipsilateral distractor, and contralateral distractor), target side (left vs. right), and laterality (hemisphere contralateral vs. ipsilateral to the target side). In these analyses, the presence of reliable lateralized components is reflected by the main effect of the factor laterality, indicating significant differences between the hemisphere contralateral and ipsilateral to the target side. Following significant laterality x type of trial interactions, separate analyses were carried out for each type of trial, to determine the presence of reliable N140cc lateralized components. Then, the amplitude of these N140cc were then calculated by subtracting the ERPs elicited at electrodes ipsilateral to the target from contralateral ERPs, separately for the different types of trials. To determine whether the N140cc amplitude was modulated by the presence and location of the distractor, we run planned contrasts between the lateralizations observed on target only trials and all other types of trials (distractor only, ipsilateral and contralateral distractor trials) and between ipsilateral and contralateral distractor trials. The p values were adjusted following the Bonferroni method.

In line with the behavioral data analysis strategy, we assessed the impact of stimulus saliency on the attentional processes of target selection through additional mixed ANOVAs including Experiment as between-subjects factor. In these analyses, reported in the General analyses section, we were specifically interested in the type of trial x laterality x experiment interactions. Following this, separate mixed ANOVAs with laterality as within-subject factor and experiments as between-subject factor were carried out separately for each type of trial.

Whenever sphericity was violated (as defined by the Mauchly's test), we reported the original degrees of freedom together with the Greenhouse–Geisser values (reported as ε). Bonferroni-corrected p values and the number of comparisons are reported for all follow-up analyses.

3 | RESULTS

3.1 | Behavioral results

3.1.1 | Accuracy

Experiment 1

Results of the ANOVA carried out on accuracy rates showed a main effect of type of trial ($F(2, 38) = 49.52$, $\varepsilon = .75$, $p < .001$, $\eta_p^2 = .72$). Planned contrasts between different trial types (three comparisons) revealed that responses on target only trials were more accurate than those on ipsilateral distractor trials (80% vs. 59%, respectively; $t(19) = 8.14$, $p < .001$, $d = 1.82$) and on contralateral distractor trials (72%; $t(19) = 5.50$, $p < .001$, $d = .76$). Responses were less accurate on ipsilateral than contralateral distractor trials ($t(19) = -5.91$, $p < .001$, $d = -1.06$). Accuracy results of Experiment 1 are shown in Figure 1, left panel.

Experiment 2

Analyses of accuracy rates revealed a significant main effect of type of trial ($F(2, 38) = 110.06$, $p < .001$, $\eta_p^2 = .85$). Similarly to Exp. 1, planned contrasts (three comparisons) showed that responses were significantly more accurate on target only trials than on ipsilateral (88% vs. 50%, respectively; $t(19) = 12.89$, $p < .001$, $d = 3.98$) and contralateral distractor trials (70%; $t(19) = 8.04$, $p < .001$, $d = 1.96$). Responses were more accurate on contralateral than on ipsilateral distractor trials ($t(19) = -8.17$, $p < .001$, $d = -1.97$). Accuracy results of Experiment 2 are shown in Figure 1, right panel.

General analysis

Results of the mixed ANOVA on accuracy rates with experiment as between-subject factor and type of trial as within subject factor revealed a significant interaction between type of trial and experiment ($F(2, 76) = 12.18$, $\varepsilon = .84$, $p < .001$, $\eta_p^2 = .24$). Follow-up contrasts conducted separately for each type of trial (three comparisons) revealed significant differences between experiments for *target only* trials ($t(36.15) = -2.61$, $p = .039$, $d = -.83$). Responses were more accurate in Exp. 2 than in Exp. 1 (88% vs. 80%, respectively). Differences between experiments approached significance on ipsilateral distractor trials ($t(36.94) = 2.41$, $p = .06$, $d = .76$), while were not present on contralateral distractor trials, $t(36.98) = .51$, $p = 1.8$, $d = .16$).

Finally, the between-experiment analysis of distractor-presence costs for accuracy revealed a main effect of experiment ($F(1, 38) = 19.38$, $p < .001$, $\eta_p^2 = .34$), as target-presence costs were more pronounced in Exp. 2 than in Exp. 1 (28% vs. 15%, respectively). We also observed a significant main effect of distractor type ($F(1, 38) = 100.71$, $p < .001$, $\eta_p^2 = .73$), as accuracy costs on ipsilateral distractor trials were stronger than those observed on contralateral distractor trials (30% vs. 13%, respectively). Results also showed a significant type of distractor x experiment interaction ($F(1, 38) = 4.91$, $p = .033$, $\eta_p^2 = .11$). Follow-up contrasts carried out separately for each type of distractor-present trial (ipsilateral vs. contralateral distractor, two comparisons), revealed stronger distractor-presence costs in Exp. 2 than in Exp. 1 for both ipsilateral (38% and 21%, respectively, $t(37.53) = 4.19$, $p < .001$, $d = 1.32$) and contralateral distractor trials (17% and 8%, respectively, $t(33.95) = 3.45$, $p = .003$, $d = 1.09$).

3.1.2 | Reaction times

Experiment 1

The ANOVA carried out on RTs revealed a significant main effect of type of trial ($F(2, 38) = 29.12$, $p < .001$, $\eta_p^2 = .61$). Planned contrasts (three comparisons) indicated that responses on target only trials were significantly faster than those on ipsilateral distractor trials (810 ms vs. 866 ms, respectively, $p < .001$, $t(19) = -6.27$, $d = -.40$) and those
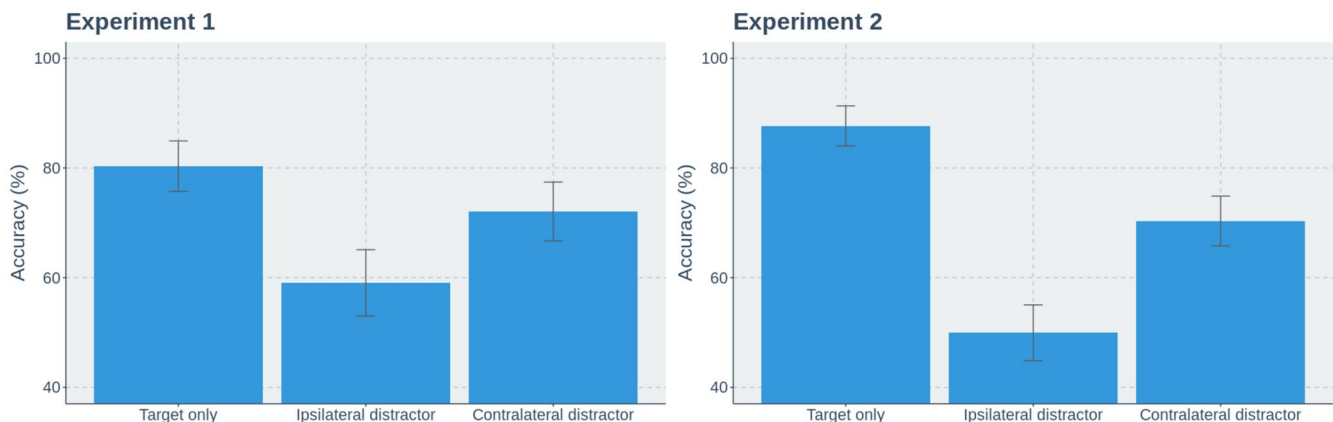

FIGURE 1 Mean error rates shown separately for the target-present search arrays (target only, ipsilateral distractor, contralateral distractor) in Experiment 1 (left panel) and Experiment 2 (right panel) in which participants searched for the lowest or highest vibro-tactile frequency in the search array, respectively. Error bars represent 95% confidence intervals

on contralateral distractor trials (830 ms, $p = .006$, $t(19) = -3.59$, $d = -.16$). Ipsilateral distractor responses were significantly slower than contralateral distractor ones ($p < .001$, $t(19) = 4.83$, $d = .28$). RT results of Experiment 1 are shown in Figure 2, left panel.

Experiment 2

RT results showed a significant main effect of trials type ($F(2, 38) = 65.11$, $p < .001$, $\eta_p^2 = .77$). Planned contrasts (three comparisons) indicated that responses were significantly faster on target only trials than on ipsilateral distractor trials (785 ms vs. 912 ms, respectively; $t(19) = -9.58$, $p < .001$, $d = -.91$) and on contralateral distractor trials (850 ms; $t(19) = -8.08$, $p < .001$, $d = -.53$). Furthermore, responses were significantly faster on contralateral distractor trials than on ipsilateral distractor trials ($t(19) = 5.33$, $p < .001$, $d = .45$). RT results of Experiment 2 are shown in Figure 2, right panel.

General analysis

In the mixed ANOVA carried out on RTs, we observed a significant type of trial x experiment interaction ($F(2, 76) = 13.90$, $\varepsilon = .80$, $p < .001$, $\eta_p^2 = .27$). Follow-up contrasts were conducted separately for each type of trial (three comparisons). No significant difference between experiments was observed in any of these comparisons (target only trials, $t(38) = 0.76$, $p = 1.35$, $d = .24$; ipsilateral distractor trials, $t(37.90) = -1.05$, $p = .9$, $d = -.33$; and contralateral distractor, $t(37.94) = -0.55$, $p = 1.76$, $d = -.17$).

The between-experiment analyses carried out on reaction times costs showed a main effect of experiment ($F(1, 38) = 25.54$, $p < .001$, $\eta_p^2 = .4$). Responses were on average 37 ms slower on distractor-present than on distractor-absent trials in Exp. 1, whereas this difference increased to 94 ms in Exp. 2. We also observed a significant main effect of distractor type ($F(1,38) = 50.70$, $p < .001$, $\eta_p^2 = .57$), as shown by stronger distractor-presence costs on ipsilateral than contralateral

distractor trials (89 ms vs. 42 ms, respectively). No significant type of distractor x experiment interaction emerged in this analysis ($F(1,38) = 2.91$, $p = .096$, $\eta_p^2 = .07$). For both ipsilateral and contralateral distractor trials, distractor-presence costs were higher in Exp. 2 than in Exp. 1 (for ipsilateral distractor: 123 ms in Exp. 2 vs. 55 ms in Exp. 1, $t(33.69) = -4.34$, $p < .001$, $d = -1.37$; for contralateral distractor, 64 ms in Exp. 2 vs. 19 ms in Exp. 1, $t(33.5) = -4.66$, $p < .001$, $d = -1.47$).

3.2 | ERP results

3.2.1 | Experiment 1

Figure 3 shows the somatosensory ERP waveforms elicited by the four different tactile search arrays (types of trials) over the hemisphere contralateral and ipsilateral to the target side (or to the distractor side on distractor only trials) in Experiment 1. This figure suggests that the presence of a singleton distractor on distractor trials elicited a distractor-related N140cc. In addition, the target-related N140cc was smaller on contralateral distractor trials as compared to target only trials.

Statistical analyses showed a significant main effect of laterality for both the 140–240 ms ($F(1, 19) = 18$, $p < .001$, $\eta_p^2 = .49$) and the 240–430 ms time windows ($F(1, 19) = 29.5$, $p < .001$, $\eta_p^2 = .6$), reflecting the overall presence of a statistically reliable N140cc component between 140 and 340 ms post-stimulus. Crucially, significant type of trial x laterality interactions were observed in both time windows (140–240 ms time window, $F(1, 19) = 6.1$, $p = .008$, $\eta_p^2 = .24$; 240–430 ms time window, $F(1, 19) = 16.3$, $p < .001$, $\eta_p^2 = .46$), confirming that the amplitude of the N140cc component was modulated by the presence the salient distractor (Figure 3).
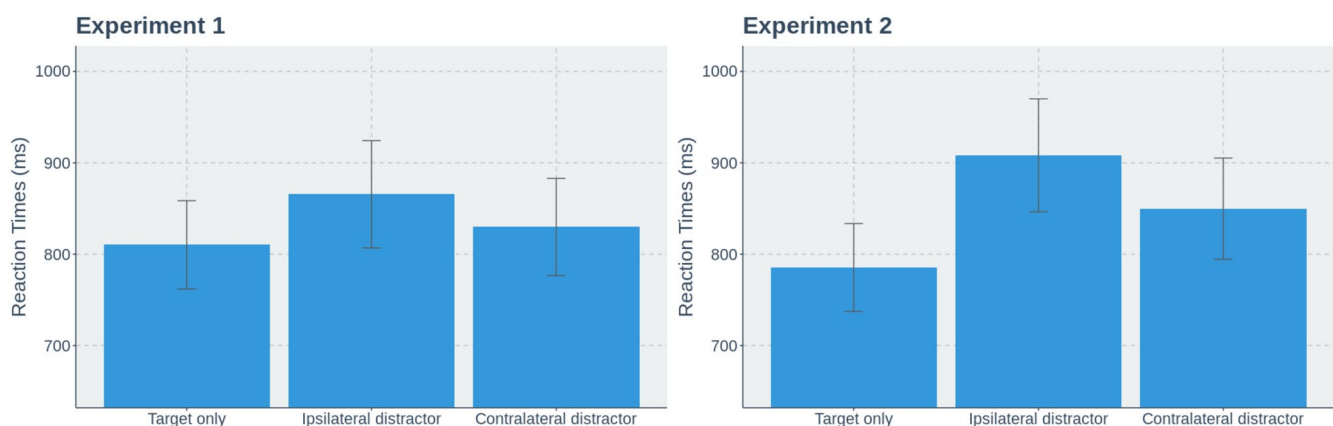

FIGURE 2 Mean reaction times shown separately for the target-present search arrays (target only, ipsilateral distractor, contralateral distractor) in Experiment 1 (left panel) and Experiment 2 (right panel) in which participants searched for the lowest or highest vibro-tactile frequency in the search array, respectively. Error bars represent 95% confidence intervals
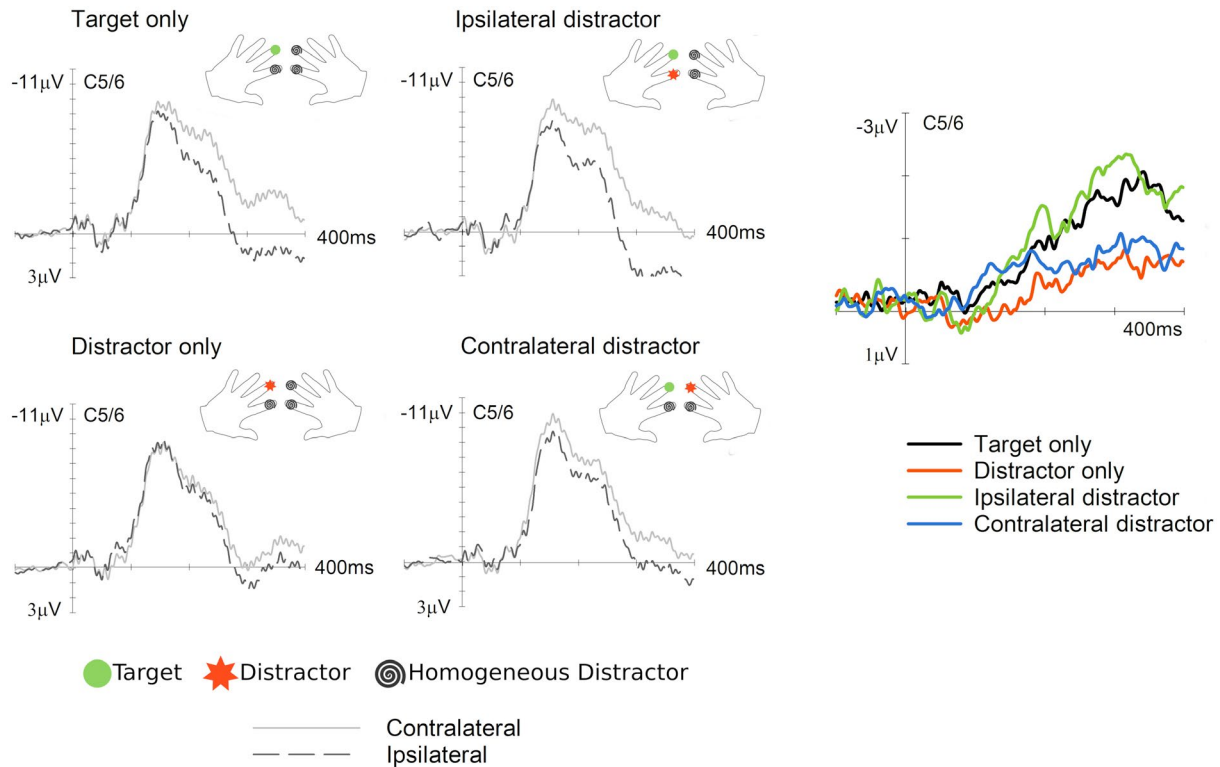
FIGURE 3   Grand-averaged ERPs elicited by the search arrays over the hemisphere contralateral (solid grey line) and ipsilateral (dashed black line) to the target in the different types of trials of Experiment 1. In this experiment the frequencies of target, singleton distractor, and homogeneous distractors were 12.5, 40, and 100 Hz, respectively. The corresponding difference waveforms calculated separately for the different trials types are shown in the right panel. Note that on distractor only trials the lateralizations shown are contralateral to the singleton distractor

To establish whether significant N140cc were present on the different types of trials separate ANOVAs were carried out for each of these different search array. On *target only* trials, the N140cc was observed in both 140–240 ms and 240–430 ms time windows (140–240 ms, $F(1, 19) = 19.4$, $p < .001$, $\eta_p^2 = .5$; 240–430 ms, $F(1, 19) = 27$, $p < .001$, $\eta_p^2 = .59$). On *distractor only* trials, the N140cc approached significance between 140 and 240 ms post-array onset ($F(1, 19) = 2.4$, $p = .14$, $\eta_p^2 = .11$), but was reliably present in the 240–430 ms time window ($F(1, 19) = 17.9$, $p < .001$, $\eta_p^2 = .49$). On *ipsilateral distractor* trials, there was a significant N140cc in both time windows (140–240 ms, $F(1, 19) = 11.5$, $p = .003$, $\eta_p^2 = .38$; 240–430 ms, $F(1, 19) = 29.6$, $p < .001$, $\eta_p^2 = .6$). Similarly, a reliable N140cc was observed on *contralateral distractor trials* between 140 and 340 ms post-array onset (140–240 ms, $F(1, 19) = 12.8$, $p = .002$, $\eta_p^2 = .4$; 240–430 ms, $F(1, 19) = 13.5$, $p = .001$, $\eta_p^2 = .4$).

To further explore the interaction between type of trial and laterality, four theoretically driven paired comparisons were carried out on the N140cc amplitudes computed by subtracting ERPs elicited at electrode C5/6 ipsilateral to the target from contralateral ERPs. The target-related N140cc on target only trials was larger than the distractor-related N140cc on distractor only trials in both time windows considered (140–240 ms, $t(19) = 3.8$, $p = .004$; 240–430 ms, $t(19) =$

4.1, $p = .004$). When the target-related N140cc observed on target only trials was compared to that measured on ipsilateral distractor trials, no differences emerged between 140 and 340 ms post-array onset (target only vs. ipsilateral distractor, 140–240 ms time window, $t(19) = 1.3$, $p = .76$; 240–340 ms time window, $t(19) = 1.7$, $p = .4$). The amplitude of the N140cc was larger on target only than on contralateral distractor trials between 240 and 340 ms post-stimulus, $t(19) = 4.1$, $p < .001$ (but not in the early time window, 140–240 ms, $(t(19) = 1.1$, $p = 1.12$). Finally, the N140cc was larger on ipsilateral than contralateral distractor trials in the late time windows, 240–340 ms, $t(19) = 5.6$, $p < .001$ (while this difference in the 140–240 ms interval did not reach significance after Bonferroni adjustment, $t(19) = 2.2$, $p = .152$).

3.2.2 | Experiment 2

Figure 4 shows the somatosensory ERP waveforms elicited by the four different tactile search arrays (types of trials) over the hemisphere contralateral and ipsilateral to the target side (or to the distractor side on distractor only trials) in Experiment 2. As can be seen in this figure, a distractor-related N140cc component was elicited contralateral to the distractor on distractor only trials. Similarly to what observed
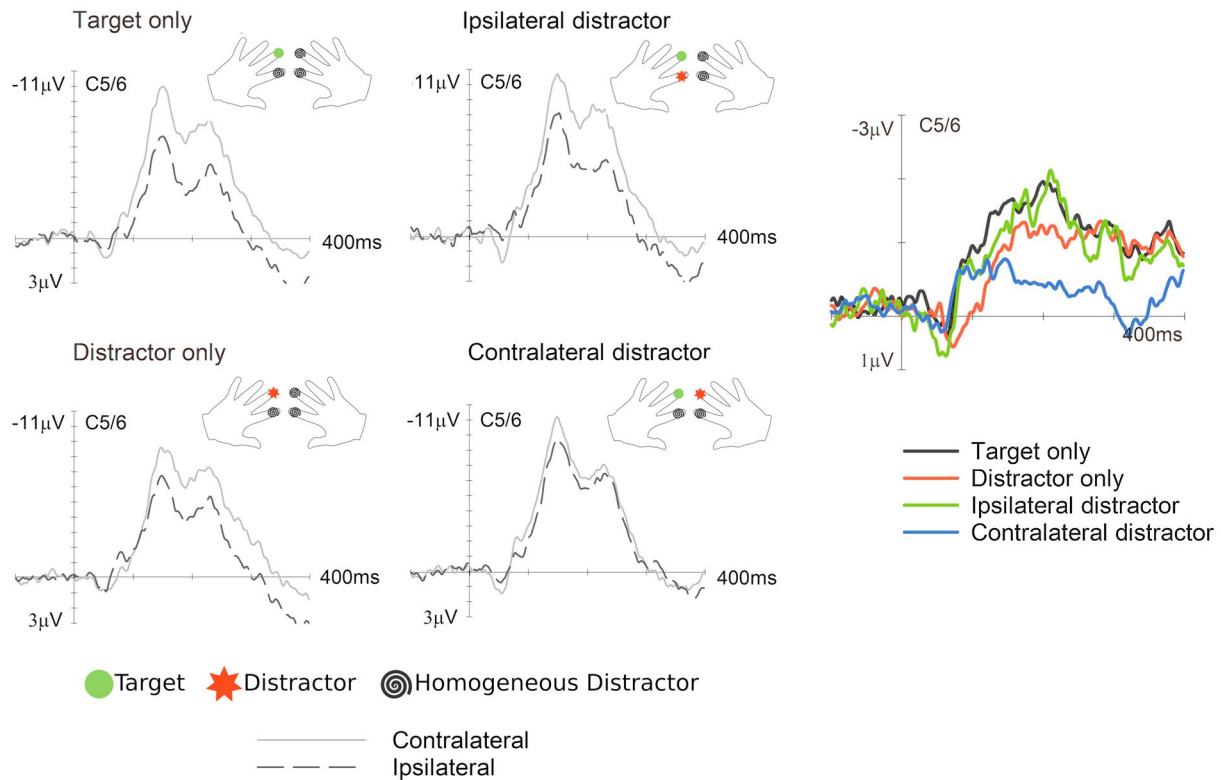
FIGURE 4 Grand-averaged ERPs elicited by the search arrays over the hemisphere contralateral (solid grey line) and ipsilateral (dashed black line) to the target in the different types of trials of Experiment 2. In this experiment the frequencies of target, singleton distractor, and homogeneous distractors were 100, 40, and 12.5 Hz, respectively. The corresponding difference waveforms calculated separately for the different trials types are shown in the right panel. Note that on distractor only trials the lateralizations shown are contralateral to the singleton distractor

in Experiment 1, the amplitude of the target-related N140cc was reduced on contralateral distractor trials as compared to target only trials. However, the N140cc observed on target only trials was comparable to that obtained on ipsilateral distractor trials.

ANOVAs carried out on the mean amplitude ERPs values measured in the 140–240 and 240–340 ms time windows revealed the presence of a reliable N140cc component in both these intervals (main effects of laterality, 140–240 ms, $F(1, 19) = 52.3$, $p < .001$, $\eta_p^2 = .73$; 240–340 ms, $F(1, 19) = 24.7$, $p < .001$, $\eta_p^2 = .56$). Significant type of trial x laterality interactions were present in both time windows (140–240 ms, $F(1, 19) = 15.1$, $p < .001$, $\eta_p^2 = .44$; 240–340 ms, $F(1, 19) = 13.7$, $p < .001$, $\eta_p^2 = .4$), demonstrating that different N140cc were elicited on different types of trial (Figure 4).

First, follow-up analyses were carried out to verify the statistical presence of the N140cc component in the different types of trials. On *target only* trials, the N140cc was observed in both 140–240 and 240–340 ms time windows ($F(1, 19) = 70.7$, $p < .001$, $\eta_p^2 = .79$ and $F(1, 19) = 34.5$, $p < .001$, $\eta_p^2 = .65$, respectively). Likewise, on *distractor only* trials, the N140cc was significantly present between 140 and 240 ms ($F(1, 19) = 91.4$, $p < .001$, $\eta_p^2 = .8$), and

between 240 and 340 ms post-array onset ($F(1, 19) = 54.9$, $p < .001$, $\eta_p^2 = .7$). The N140cc was present in both time windows also on *ipsilateral distractor trials* (140–240 ms, $F(1, 19) = 23.9$, $p < .001$, $\eta_p^2 = .56$; 240–430 ms, $F(1, 19) = 9.5$, $p < .006$, $\eta_p^2 = .33$). On *contralateral distractor* trials, the main effect of laterality was present between 140 and 240 ms post-array onset ($F(1, 19) = 8.9$, $p < .007$, $\eta_p^2 = .32$), but not between 240–340 ms post-stimulus ($F(1, 19) = 0.9$, $p = .76$, $\eta_p^2 = .005$).

Second, the amplitude of the N140cc was computed by subtracting ERPs elicited at electrode C5/6 ipsilateral to the target from contralateral ERPs separately for each type of trials. These difference amplitudes values reflecting the N140cc amplitudes measured in the different types of trials were then compared through four planned contrasts our comparisons. The target-elicited N140cc on target only trials was larger than the distractor-elicited N140cc on distractor only trials in the 140–240 time window ($t(19) = 3$, $p = .028$), but not in the 240–340 ms time window ($t(19) = 0.09$, $p = 3.6$). No difference emerged between the target-elicited N140cc observed on target only trials and on ipsilateral distractor trials between 140 and 340 ms post-stimulus (140–240 ms, $t(19) = 0.3$, $p = 2.8$; 240–340 ms, $t(19) = 0.9$, $p = 1.48$). The N140cc on target only trials was larger than that observed on

contralateral distractor trials between 140 and 340 ms post-array onset (140–240 ms, $t(19) = 8.2$, $p < .001$; 240–340 ms, $t(19) = 6.5$, $p < .001$). A larger N140cc was also observed on ipsilateral than contralateral distractor trials (140–240 ms, $t(19) = 4.4$, $p < .001$; 240–340 ms, $t(19) = 3.3$, $p = .012$).

3.2.3 | General analysis

In the ERP analyses carried out between experiments, significant type of trial x laterality x experiment interaction emerged in both time windows considered (140–240 ms, $F(3, 114) = 6.3$, $p < .001$, $\eta_p^2 = .14$; 240–340 ms, $F(3, 114) = 10$, $p < .001$, $\eta_p^2 = .21$). Follow-up mixed ANOVAs including the factors laterality and experiment were carried out separately for each type of trial. Differences between the N140cc elicited on *target only* trials were observed between 140 and 240 ms post-stimulus onset ($F(1, 38) = 11.2$, $p = .002$, $\eta_p^2 = .22$), as the N140cc reached its maximal amplitude earlier in Exp. 2 than in Exp. 1. Furthermore, the distractor-related N140cc was larger in Exp. 2 than in Exp. 1 on *distractor only* trials in both time windows (140–240 ms, $F(1, 38) = 43.9$, $p < .001$, $\eta_p^2 = .53$; 240–340 ms, $F(1, 38) = 7$, $p < .011$, $\eta_p^2 = .16$). The target-related N140cc observed on *ipsilateral distractor* trials differed between experiments in the later 240–340 time window considered ($F(1, 38) = 5.4$, $p < .025$, $\eta_p^2 = .12$). This difference reflected the presence of larger N140cc amplitudes on *ipsilateral distractor* trials in Exp. 1 than in Exp. 2. Finally, on *contralateral distractor* trials the target-related N140cc was smaller in Exp. 2 than in Exp. 1 in the 240–340 time window ($F(1, 38) = 9$, $p < .005$, $\eta_p^2 = .19$).

4 | DISCUSSION

The aim of the present study was to investigate the electro-physiological correlates of target selection as indexed by the N140cc in a tactile search task in which a singleton distractor was presented simultaneously with the target in the search array. In two experiments, participants were asked to identify the elevation (top vs. bottom location) of the target defined by the slowest (12.5 Hz in Exp. 1) or fastest vibration (100 Hz in Exp. 2) in a four-items search array, while ignoring all stimuli characterized by the other frequencies. Notably, despite the fact that there were differences between experiments driven by the physical properties of the stimuli, the pattern of results (differences between the N140cc components) on different types of trials were similar across experiments, suggesting that analogous attentional mechanisms were operating regardless of the relative saliency of target and distractors. The correlates of target selection in the presence of a singleton distractor will be considered first, followed by a discussion of the saliency effects observed in the two studies. ERPs elicited

by the presentation of the search array were recorded over the somatosensory cortex ipsilateral and contralateral to the hand where the target was presented. As expected on *target only trials*, ERPs elicited over the hemisphere contralateral to the target were more negative than those elicited over the ipsilateral hemisphere, in line with existing evidence from tactile search ERP studies (e.g., Ambron et al., 2018; Forster et al., 2016; Katus & Eimer, 2019). Importantly, reliable lateralizations were also observed in both experiments contralateral to the distractor when this singleton was presented among homogeneous distractors on target-absent trials. This suggests that attention was directed to the distractor when the target was not present in the search array (*distractor only trials*), similarly to what has been reported in visual search studies (e.g., Hilimire & Corballis, 2014). However, the reduced N140cc amplitudes observed on distractor only trials as compared to target only trials indicated that reduced attentional resources were directed to the singleton when this was task-irrelevant.

To investigate whether the presence of the distractor affects the attentional selection of the target, it is necessary to consider trials in which both singletons compete for representation. Behavioral results showed clear distractor-presence costs, with slower and less accurate responses on ipsilateral and contralateral distractor trials as compared to target only trials, suggesting that the irrelevant frequency-singleton distractor interfered with the selection of the task-relevant target frequency. Distractor-presence costs were generally higher when the distractor was ipsilateral than contralateral to the target. This reveals that the target-distractor interference was not simply due to the presence of an additional singleton item in the search array but was mediated by their relative distance in line with existing evidence from visual search studies (e.g., Hickey & Theeuwes, 2011; McCarley, Mounts, & Kramer, 2007; Mounts, 2000).

ERPs measured on *contralateral distractor trials,* in which target and distractor were presented to different hands, revealed the presence of a target-related N140cc. However, the N140cc amplitude on contralateral distractor trials was strongly reduced as compared to that observed on both target only and ipsilateral distractor trials. This may indicate that reduced attentional resources were directed to the target when the distractor was presented to the opposite hand or that, on some trials, attention was directed to the distractor on the opposite hand rather than to the target, reducing the overall amplitude of the target-related N140cc. On *ipsilateral distractor trials*, a reliable N140cc was observed contralateral to the side of the two singletons. This component was larger than the N140cc on contralateral distractor trials, but did not differ from that observed on target only trials. Thus, the deployment of attention to the target as indexed by the N140cc was similar on target only and ipsilateral distractor trials. Instead, the singleton distractor delayed the localization of the target

within the attended hand, as revealed by distractor-presence costs.

Results of the present study revealed that the presence of the singleton distractor affected the deployment of attention to the target, as indexed by the N140cc, when these singletons were presented to opposite hands. Behavioral studies have suggested that tactile search tasks are characterized by inefficient serial processing (e.g., Halfen, Magnotti, & Yau, 2019; Overvliet, Smeets, & Brenner, 2007; Toet, Groen, Oosterbeek, & Hooge, 2008). Because some tactile features, including stimuli vibro-tactile frequencies, cannot be fully processed pre-attentively, the selection of the target requires the attentional processing of the distractor(s). In line with this hypothesis, we observed that attention was directed at least in part to the singleton distractor, when it was the only singleton in the array (distractor only) and when it was opposite to the target (contralateral distractor). By contrast, the deployment of attention to the target was relatively unaffected by the presence of the singleton distractor on the adjacent finger of the same hand (ipsilateral distractor). That is, comparable attentional resources were directed to the target side regardless of the type of distractor presented next to it (singleton or homogeneous distractor), as revealed by the similar N140cc observed on ipsilateral distractor and target only trials. This may suggest that the N140cc component does not reflect the filtering mechanisms responsible for the resolution of local (within-hand) ambiguity. Because target-distractor competitive interactions were clearly present in our study, as demonstrated by distractor-presence costs on ipsilateral distractor trials, it is possible that these were solved through non-lateralized mechanisms in a way that was not reflected by the N140cc lateralized component or that the conflict between stimuli arose during later response selection stages.[2] Overall, the pattern of lateralized ERP components observed in the present study suggests that the N140cc reflects primarily the selection of the hand where the target is presented (i.e., the global allocation of attention to one hand vs. the other), whereas it is relatively unaffected by competitive or suppressive target-distractor interactions within that hand.

Interestingly, several observations from visual search studies in which participants searched for a known target have shown that the increased target-distractor interference observed on ipsilateral distractor trials reflects distractor-related inhibitory processes which slow/hinder the processing of the nearby target (Hickey & Theeuwes, 2011; Mounts, 2000). Electrophysiological evidence has shown systematic N2pc reductions when both target and distractor were present in the search array as compared to target only trials (e.g., Hilimire & Corballis, 2014). A similar N2pc reduction was also observed when both singletons were on the same side of the search array as compared to lateral target trials in which the distractor was presented on the midline (e.g., Gaspar & McDonald, 2014). These findings show that the N2pc

is modulated by the competitive influence of the distractor on the target and is sensitive to the presence of localized attentionally mediated competition between these singletons. Although it has been suggested that the N140cc is the equivalent of the visual N2pc observed in visual search tasks, our results indicate that there might be relevant differences between the functional significance of these components.

An additional aim of this project was to determine the impact of stimulus saliency on the attentional mechanisms of target selection. Previous studies in touch have suggested that responding to targets characterized by the greater intensity of a feature is less demanding than searching for the absence or the lesser intensity of a feature (e.g., Forster & Eimer, 2004; Whang, Burton, & Shulman, 1991). The target singleton was characterized by the lowest vibro-tactile frequency in the search array in Experiment 1 and by the highest frequency in Experiment 2, respectively, and was therefore, the least or most salient item. The direct comparison of results between experiments revealed faster responses on *target only trials* in Exp. 2 than in Exp. 1, confirming that the target localization occurred more quickly for more salient targets. Furthermore, stronger distractor-presence costs were present in Exp. 2 than in Exp. 1. This increased difference between distractor-absent and distractor-present trials in Exp. 2 is at least in part driven by the improved performance recorded on target only trials when the target was more salient. The effect of stimulus saliency on target selection has been well documented in visual search ERP studies in which more salient targets led to larger and earlier N2pc components (e.g., Gaspar & McDonald, 2014; Luck et al., 2006; Töllner, Zehetleitner, Gramann, & Müller, 2011). In line with these findings, we observed a larger N140cc in Exp. 2 than in Exp. 1 on *target only* trials in the early time window (140–240 ms) suggesting that attentional resources were deployed more readily toward the target side when the target was the most salient item in the search array. In addition, attention was more likely to be directed to the singleton distractor when this was more salient than the homogeneous distractor (in Exp. 2 as compared to in Exp. 1), as demonstrated by the reduced amplitude of the target-elicited N140cc observed on *contralateral distractor* trials and the increased distractor-elicited 140cc amplitude observed on *distractor only trials*.

The manipulation of saliency allowed us to assess the possibility that the ERP differences observed between different types of trials were driven primarily by sensory imbalances embedded in the tactile search arrays (i.e., stimuli of different frequencies presented to the different hands). If the N140cc reflected exclusively sensory asymmetries between hemispheres, its amplitude should be maximal on ipsilateral distractor trials when the two singletons are on the same hand. This saliency-driven effect should be more evident in Exp. 2 because the frequencies of target and distractor were more salient than those of the homogeneous distractors. In contrast to this, similar N140cc components

PSYCHOPHYSIOLOGY SPR

were observed on ipsilateral distractor and target only trials in both experiments, regardless of stimulus salience. Furthermore, the N140cc amplitude was larger on target only than on distractor only trials in both studies, despite the fact that the target frequency was more salient than the distractor one in Exp. 2 but not in Exp. 1. Thus, although it is likely that sensory asymmetries contributed to the N140cc amplitudes, cognitive factors primarily determined the presence and characteristics of this component in the different experimental conditions.

In summary, results of the present studies demonstrated for the first time that the presence of a singleton distractor was detrimental for the selection of the tactile target in a tactile search task. Responses were slower and less accurate when the singleton distractor was present. Furthermore, ERP results showed that attention was directed to the distractor when this was the only singleton in the search array (distractor only trials) and when it was presented to the opposite hand with respect to the target (contralateral distractor trials). However, the N140cc amplitude was not modulated by the increased target-distractor competition that characterized ipsilateral distractor trials. These findings suggests that the tactile N140cc might reflect the general deployment of attention to the task-relevant hand rather than the specific filtering processes associated with the selection of the task-relevant stimulus.

ORCID

Carlos I. Mena [iD] https://orcid.org/0000-0003-2189-8676
Elena Gherri [iD] https://orcid.org/0000-0003-2575-9729

ENDNOTES

[1] Because both target and distractor were equally likely to appear at any of the four locations in the search array, when they were presented to opposite hands (contralateral distractor trials) they could appear either both at the top location (target-distractor congruent locations) or one at the top and one at the bottom location (target-distractor incongruent locations). These two types of trials were collapsed as they were considered theoretically equivalent and no difference emerged between congruent and incongruent contralateral distractor trials in the ERP analysis of Exp. 1 (trial type, congruent vs. incongruent, x laterality, $F(1, 19) < 0.09$, $p > .7$, for both time windows considered) and of Exp. 2 (trial type, congruent vs. incongruent, x laterality, $F(1, 19) < 2.2$, $p > .15$, for both time windows considered). However, behavioural results showed that response selection was more accurate on congruent than incongruent contralateral distractor trials in Exp. 1 (accuracy: 76.22% and 67.81%, respectively, $t(19) = 4.09$, $p = .003$, $d = .91$; speed: 828 and 835 ms, respectively, $t(19) = -1.17$, $p = 1.03$, $d = -.26$) and in Exp. 2 (accuracy: 81.4% and 60.6%, respectively; $p < .001$, $t(20) = 8.39$, $d = 1.83$; RTs: 819 and 896 ms, respectively; $p < .001$, $t(19) = -7.56$, $d = -1.65$). Thus, it is likely that a response was activated for both target and distractor singletons, creating a conflict during the response selection stage, and delaying further the selection and execution of the correct response when these singletons were presented at incongruent locations.

[2] This latter possibility is directly supported by the direct comparison of congruent and incongruent contralateral distractor trials in which target and distractors singletons were presented to opposite hands at the same or at different elevations, respectively, see Footnote 1. While the allocation of attention indexed by the N140cc was relatively unaffected by the different elevation of target and distractor on these trials, there was a clear conflict between the singletons locations in the behavioural results, suggesting that later processing stages such as response selection and execution were affected by it.

REFERENCES

Ambron, E., Mas-Casadesús, A., & Gherri, E. (2018). Hand distance modulates the electrophysiological correlates of target selection during a tactile search task. *Psychophysiology*, 55(8), e13080. https://doi.org/10.1111/psyp.13080

Burra, N., & Kerzel, D. (2013). Attentional capture during visual search is attenuated by target predictability: Evidence from the N2pc, Pd, and topographic segmentation. *Psychophysiology*, 50(5), 422–430. https://doi.org/10.1111/psyp.12019

Desimone, R., & Duncan, J. (1995). Neural mechanisms of selective visual attention. *Annual Review of Neuroscience*, 18(1), 193–222. https://doi.org/10.1146/annurev.ne.18.030195.001205

Eimer, M. (1996). The N2pc component as an indicator of attentional selectivity. *Electroencephalography and Clinical Neurophysiology*, 99(3), 225–234. https://doi.org/10.1016/0013-4694(96)95711-9

Eimer, M. (2014). The neural basis of attentional control in visual search. *Trends in Cognitive Sciences*, 18(10), 526–535. https://doi.org/10.1016/j.tics.2014.05.005

Forster, B., & Eimer, M. (2004). The attentional selection of spatial and non-spatial attributes in touch: ERP evidence for parallel and independent processes. *Biological Psychology*, 66(1), 1–20. https://doi.org/10.1016/J.BIOPSYCHO.2003.08.001

Forster, B., Tziraki, M., & Jones, A. (2016). The attentive homunculus: ERP evidence for somatotopic allocation of attention in tactile search. *Neuropsychologia*, 84, 158–166. https://doi.org/10.1016/J.NEUROPSYCHOLOGIA.2016.02.009

Gaspar, J. M., Christie, G. J., Prime, D. J., Jolicœur, P., & McDonald, J. J. (2016). Inability to suppress salient distractors predicts low visual working memory capacity. *Proceedings of the National Academy of Sciences of the United States of America*, 113(13), 3693–3698. https://doi.org/10.1073/pnas.1523471113

Gaspar, J. M., & McDonald, J. J. (2014). Suppression of salient objects prevents distraction in visual search. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, 34(16), 5658–5666. https://doi.org/10.1523/JNEUROSCI.4161-13.2014

Gaspelin, N., & Luck, S. J. (2018). The role of inhibition in avoiding distraction by salient stimuli. *Trends in Cognitive Sciences*, 22(1), 79–92. https://doi.org/10.1016/j.tics.2017.11.001

Halfen, E. J., Magnotti, J. F., Rahman, M. S., & Yau, J. M. (2019). Principles of tactile search over the body. *Journal of Neurophysiology*, 1–40. https://doi.org/10.1152/jn.00694.2019

Hickey, C., McDonald, J. J., & Theeuwes, J. (2006). Electrophysiological evidence of the capture of visual attention. *Journal of Cognitive Neuroscience*, 18(4), 604–613. https://doi.org/10.1162/jocn.2006.18.4.604

Hickey, C., & Theeuwes, J. (2011). Context and competition in the capture of visual attention. *Attention, Perception, & Psychophysics*, *73*(7), 2053–2064. https://doi.org/10.3758/s13414-011-0168-9

Hilimire, M. R., & Corballis, P. M. (2014). Event-related potentials reveal the effect of prior knowledge on competition for representation and attentional capture. *Psychophysiology*, *51*(1), 22–35. https://doi.org/10.1111/psyp.12154

Hilimire, M. R., Mounts, J. R. W., Parks, N. A., & Corballis, P. M. (2009). Competitive interaction degrades target selection: An ERP study. *Psychophysiology*, *46*(5), 1080–1089. https://doi.org/10.1111/j.1469-8986.2009.00846.x

Katus, T., & Eimer, M. (2019). The N2cc component as an electrophysiological marker of space-based and feature-based attentional target selection processes in touch. *Psychophysiology*, *56*(9), e13391. https://doi.org/10.1111/psyp.13391

Katus, T., Grubert, A., & Eimer, M. (2015). Electrophysiological evidence for a sensory recruitment model of somatosensory working memory. *Cerebral Cortex*, *25*(12), 4697–4703. https://doi.org/10.1093/cercor/bhu153

Kiss, M., Driver, J., & Eimer, M. (2009). Reward priority of visual target singletons modulates event-related potential signatures of attentional selection. *Psychological Science*, *20*(2), 245–251. https://doi.org/10.1111/j.1467-9280.2009.02281.x

Kiss, M., Grubert, A., Petersen, A., & Eimer, M. (2012). Attentional capture by salient distractors during visual search is determined by temporal task demands. *Journal of Cognitive Neuroscience*, *24*(3), 749–759. https://doi.org/10.1162/jocn_a_00127

Luck, S. J. (2012). Electrophysiological correlates of the focusing of attention within complex visual scenes: N2pc and related ERP components. In S. J. Luck, & E. S. Kappenman (Eds.), *The Oxford handbook of event-related potential components* (pp. 329–360). https://doi.org/10.1093/oxfordhb/9780195374148.013.0161

Luck, S. J., Fuller, R. L., Braun, E. L., Robinson, B., Summerfelt, A., & Gold, J. M. (2006). The speed of visual attention in schizophrenia: Electrophysiological and behavioral evidence. *Schizophrenia Research*, *85*(1–3), 174–195. https://doi.org/10.1016/J.SCHRES.2006.03.040

Luck, S. J., & Hillyard, S. A. (1990). Electrophysiological evidence for parallel and serial processing during visual search. *Perception & Psychophysics*, *48*(6), 603–617. https://doi.org/10.3758/BF03211606

Luck, S. J., & Hillyard, S. A. (1994). Electrophysiological correlates of feature analysis during visual search. *Psychophysiology*, *31*(3), 291–308. https://doi.org/10.1111/j.1469-8986.1994.tb02218.x

McCarley, J. S., Mounts, J. R. W., & Kramer, A. F. (2007). Spatially mediated capacity limits in attentive visual perception. *Acta Psychologica*, *126*(2), 98–119. https://doi.org/10.1016/J.ACTPSY.2006.11.004

McDonald, J. J., Green, J. J., Jannati, A., & Di Lollo, V. (2013). On the electrophysiological evidence for the capture of visual attention. *Journal of Experimental Psychology: Human Perception and Performance*, *39*(3), 849–860. https://doi.org/10.1037/a0030510

Mounts, J. R. W. (2000). Evidence for suppressive mechanisms in attentional selection: Feature singletons produce inhibitory surrounds. *Perception & Psychophysics*, *62*(5), 969–983. https://doi.org/10.3758/BF03212082

Overvliet, K. E., Smeets, J. B. J., & Brenner, E. (2007). Parallel and serial search in haptics. *Perception and Psychophysics*, *69*(7), 1059–1069. https://doi.org/10.3758/BF03193944

Toet, A., Groen, E. L., Oosterbeek, M., & Hooge, I. T. C. (2008). Vibrotactile target saliency. *Display Technologies and Applications for Defense, Security, and Avionics II*, *6956*(March), 695605. https://doi.org/10.1117/12.776121

Töllner, T., Zehetleitner, M., Gramann, K., & Müller, H. J. (2011). Stimulus saliency modulates pre-attentive processing speed in human visual cortex. *PLoS ONE*, *6*(1), e16276. https://doi.org/10.1371/journal.pone.0016276

Tukey, J. W. (1977). *Exploratory data analysis*. Reading, MA: Addison-Wesley Pub. Co.

Whang, K. C., Burton, H., & Shulman, G. L. (1991). Selective attention in vibrotactile tasks: Detecting the presence and absence of amplitude change. *Perception & Psychophysics*, *50*(2), 157–165. https://doi.org/10.3758/BF03212216

Woodman, G. F. (2013). Viewing the dynamics and control of visual attention through the lens of electrophysiology. *Vision Research*, *80*, 7–18. https://doi.org/10.1016/J.VISRES.2013.01.003