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Squeeze me, but don't tease me: Human and mechanical touch enhance visual attention and emotion discrimination

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Being touched by another person influences our readiness to empathize with and support that person. We asked whether this influence arises from somatosensory experience, the proximity to the person and/or an attribution of the somatosensory experience to the person. Moreover, we were interested in whether and how touch affects the processing of ensuing events. To this end, we presented neutral and negative pictures with or without gentle pressure to the participants' forearm. In Experiment 1, pressure was applied by a friend, applied by a tactile device and attributed to the friend, or applied by a tactile device and attributed to a computer. Across these conditions, touch enhanced event-related potential (ERP) correlates of picture processing. Pictures elicited a larger posterior N100 and a late positivity discriminated more strongly between pictures of neutral and negative content when participants were touched. Experiment 2 replicated these findings while controlling for the predictive quality of touch. Experiment 3 replaced tactile contact with a tone, which failed to enhance N100 amplitude and emotion discrimination reflected by the late positivity. This indicates that touch sensitizes ongoing cognitive and emotional processes and that this sensitization is mediated by bottom-up somatosensory processing. Moreover, touch seems to be a special sensory signal that influences recipients in the absence of conscious reflection and that promotes prosocial behavior.

Keywords: Somatosensory; Empathy; Social facilitation; Brain; Communication.

INTRODUCTION

An event that we find "touching" stirs us emotionally and makes our hearts go out to the individuals that were implicated in the event. The gentle touch from another person can have a similar effect. Researchers found that even a short tap on one's hand or forearm increases the likelihood that an interaction partner is positively appraised and supported. For example, users of a library rated the library and its personnel more favorably when they had been casually touched while receiving their library card (Fisher, Rytting, & Heslin, 1976). In the context of commercial transactions, customers were more satisfied and gave greater tips when the personnel touched them as compared to when no tactile contact ensued (Crusco & Wetzel, 1984; Erceau & Guéguen, 2007). Furthermore, individuals touched by a stranger more readily performed a favour, such as holding onto a large dog for 10 minutes while the stranger ran an errand (Guéguen & Fischer-Lokou, 2002).

Short-term tactile effects such as these are well established, yet their underlying mechanisms remain largely unknown. Psychophysiological investigations indicate that gentle touch reduces bodily arousal (Whitcher & Fisher, 1979) and emotional responses

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during fear conditioning (Coan, Schaefer, & Davidson, 2006). Additionally, neuroimaging studies suggest that touch activates brain regions implicated in emotional and social processing such as the insula and the anterior cingulate (Olausson et al., 2002; Olausson, Wessberg, Morrison, McGlone, & Vallbo, 2010). However, how these effects interleave with other aspects of an interaction such as person perception or general information processing has not yet been investigated. We set out to advance this field by characterizing the evaluation of information presented in the context of touch. Specifically, we sought to determine whether touch-dependent evaluative changes result from "bottom-up" somatosensory influences or "top-down" influences linked to the interpretation of closeness to or tactile contact with a trusted individual (Dunbar, 2008; Gallace & Spence, 2008).

Existing research makes both alternatives viable. The notion of bottom-up tactile influences accords with recent insights into the neuronal pathways underlying somatosensory perception (Olausson et al., 2002, 2010). These comprise slow-conducting mechanical receptors that are implicated in thalamic projections to emotional and social processing areas such as the insula and anterior cingulate. Importantly, these projections bypass primary somatosensory cortex involved in the conscious processing of touch, and therefore make bottom-up tactile effects neurophysiologically plausible. On the other hand, researchers found the relationship between individuals to be critical for tactile behaviour, thus pointing to a role of top-down influences. Both humans (Sugawara, 1984) and nonhuman primates show a preference for stable tactile partners (Dunbar, 2008). Moreover, long-term stress relief from tactile contact appears more effective if touch is concentrated on a few partners rather than spread around (Wittig et al., 2008). Additionally, the mere presence of a trusted individual can induce a reduction in autonomic arousal and stress (Christenfeld et al., 1997; Heinrichs, Baumgartner, Kirschbaum, & Ehlert, 2003), suggesting that perceived closeness alone could impact emotional and cognitive processes. Moreover, the actual physical contact may simply be interpreted as maximal closeness and elicit quantitatively but not qualitatively different effects from mere presence.

As apparent from the preceding discussion, one obstacle to differentiating bottom-up from top-down contributions to tactile effects has been the difficulty in dissociating the somatosensory experience from the effect of physical closeness to a trusted individual. Naturally occurring touch requires physical closeness and typically occurs between individuals that already have an established relationship (e.g., friends) or for whom the relationship is defined by the social context (e.g., waiter, customer, experimenter). Thus, past work relying on naturally occurring touch could not dissociate the two. To solve this natural confound, the present study introduced a device designed for remote tactile interaction (Teh et al., 2008). Through this device it was possible to independently vary the proximity of a trusted individual and the attribution of touch to that individual.

A second shortcoming of past research is that it relied primarily on behavioral observations or verbal reports and thus revealed little about the mental processes that are subject to tactile influences. A promising alternative is the use of online measures of peripheral and central nervous system activity. Of particular interest here is the event-related potential (ERP), whose high temporal resolution allows the study of information-processing in the millisecond range. Early deflections in the ERP, such as the N100 and P200, are highly sensitive to sensory stimulus attributes. A greater sensory salience increases their amplitude (Beauducel, Debener, Brocke, & Kayser, 2000; Hermann & Knight, 2001). Late ERP deflections, such as a posteriorly distributed late positive component (LPC), are indicative of more reflective or evaluative processes. For example, target stimuli elicit a greater LPC than nontarget stimuli (Hermann & Knight, 2001). Because early sensory processes may be modulated by top-down influences and late reflective processes may be modulated by bottom-up influences, early and late ERP deflections cannot be used to differentiate the direction of tactile influences on concurrent information processing. However, they can indicate at which point during information processing tactile influences occur.

The present study employed the mentioned tactile device and ERPs to examine the influence of touch on the processing of concurrently presented stimuli. In three separate blocks, participants viewed negative and neutral pictures while occasional tactile contact was (1) administered by and attributed to a friend, (2) administered by the touch device and attributed to a friend sitting in another room, or (3) administered by and attributed to the touch device. Given the prevailing notion that touch engenders positive attitudes and generally reduces responses to negative events (for a review see Gallace & Spence, 2008), we expected ERP processing differences between negative and neutral pictures to be smaller in the context of touch. Of particular interest were the three ERP components mentioned above. All have been shown to elicit larger amplitudes for emotional as compared to neutral stimuli, with the LPC effect being the most robust (for a review see Olofsson, Nordin, Sequeira, & Polich, 2008). Importantly, bottom-up and top-down tactile influences on these components were expected to result in block effects, with bottom-up influences being evident across blocks and top-down influences being evident only when the friend was close and/or tactile contact could be attributed to the friend.

EXPERIMENT 1

Methods

Participants

We chose to investigate touch from platonic friends because touch from a romantic partner may have a sexual connotation that was not of interest here. Furthermore, because women are typically more comfortable with touch from same-sex friends (Willis & Rawdon, 1994), 24 female participants (mean age 20.75, *SD* 1.62) and their same-sex platonic friends were invited to this study. Friendships ranged in duration from 2 months to 20 years (mean years 4.5, *SD* 5.5). The work reported here was approved by the Institutional Review Board of the National University of Singapore and concords with the 1975/1983 Helsinki Declaration on human subject rights. Accordingly, all participants and friends gave informed consent prior to the experiment.

Materials and design

Each participant completed three experimental blocks in counterbalanced order. The three blocks differed in whether touch was administered by and attributed to the friend or a touch device. In the human touch (HT) block, touch was administered by and attributed to the friend. To this end, the friend was seated next to the participant in the test room. Both were separated by a curtain and instructed not to communicate with each other. Over headphones, the friend occasionally heard tones. These tones prompted the friend to place her hand on the participant's forearm, which was accessible through a gap in the curtain. At tone offset, the friend was to remove her hand until the onset of the next tone. In the remote touch (RT) block, touch was attributed to the friend but administered by a touch device. To this end, the participant was alone in the test room with a pressure cuff attached to her forearm. The participant was told that the cuff would inflate anytime her friend pushed a connected button-box next door. While the friend was indeed operating a button-box, the inflations were controlled by a stimulus presentation program. In the mechanical touch (MT) block, the same stimulus presentation program operated the touch device. However, now the participant was informed that occasional pressure cuff inflations were computer-initiated. Thus, touch was applied through and attributed to the touch device. The onset and offset of touch in the three blocks was monitored via a pressure sensor attached to the participant's forearm. After a critical pressure threshold was exceeded a signal was sent to the stimulus presentation and data acquisition computer to mark touch onset or offset.

The stimulus material consisted of 180 negative and 180 neutral pictures from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2008). During each block, 60 negative and 60 neutral pictures were presented: half of each type during touch and the other half during no-touch trials. Pictures were not repeated within participants, but appeared equally often in the three blocks and during touch and no-touch trials across participants.

The events for touch and no-touch trials are presented in Figure 1. A touch trial started with a fixation cross. In the HT block, this coincided with a tone signal to the friend to initiate touch, while in the RT

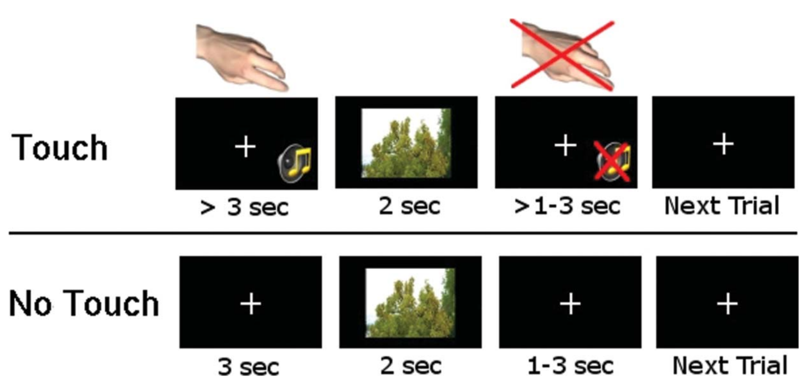

Figure 1. Events unfolding during touch and no-touch trials in Experiment 1.

and the MT blocks an inflation signal was sent to the touch device. Three seconds after tactile pressure was established, the fixation cross was replaced by a picture, which remained on the screen for 2 s. In the HT block, picture offset coincided with the offset of the tone indicating to the friend to remove her hand. In the RT and MT block, a deflation signal was sent to the pressure cuff. In all blocks, the picture was replaced by a fixation cross. The touch trial ended once tactile pressure was removed. As for the touch trials, the no-touch trials started with a fixation cross. After 3 s the cross was replaced by a picture, which remained on the screen for 2 s, after which the trial ended. Touch and no-touch trials were presented in random order with an intertrial interval (ITI) ranging from 1 to 3 s.

Procedure

Participants were seated in a chair facing a computer monitor at a distance of 0.8 m. They were asked to attend to a sequence of emotionally negative and neutral pictures and informed that their compliance with these instructions would be confirmed in a subsequent picture recognition test. Participants were asked to ignore occasional tactile stimulation to the forearm.

The EEG was recorded from 64 electrodes mounted in an elastic cap according to the modified 10–20 system. The electrooculogram (EOG) was recorded using four electrodes, which were attached above and below the right eye and at the outer canthus of each eye. Additionally, one recording electrode was placed on the nose tip. The data were recorded at 256 Hz with an ActiveTwo system from Biosemi, which uses a common mode sense active electrode for initial referencing.

After the experiment, participants were presented with 60 of the experimental images as well as new images from the IAPS that matched the old ones in valence and arousal. Participants performed an old/new judgment by pressing one of two buttons on a response box. Their responses indicated that they were able to discriminate between old and new images above chance, suggesting that they followed the experimenter's instructions.

Data analysis

EEG data were processed with EEGLab (Delorme & Makeig, 2004). The scalp recordings were re-referenced against the nose recording and a 0.1 to 30 Hz bandpass filter was applied. The continuous data were epoched and baseline corrected using a 150 ms prestimulus baseline and a 1 s time window starting from picture onset. Nontypical artifactual epochs caused by drifts or muscle movements were rejected automatically using the joint probability function in EEGLab with local and global thresholds set at three standard deviations. Infomax, an independent component analysis algorithm, was applied to the remaining data and components reflecting typical artifacts (i.e., horizontal and vertical eye movements) were removed. Back-projected single trials were screened visually for residual artifacts. The time windows for the three ERP components of interest were identified based on previously published work and visual inspection of the ERP traces. Time windows were 90 to 110 ms for the N100, 190 to 210 ms for the P200, and 300 to 500 ms for the late positivity. These time windows were selected based on visual inspection as to center on the component peak. Mean amplitudes during these time windows were subjected to separate ANOVAs with *Block* (HT/RT/MT), *Touch* (Touch/No-touch), *Emotion* (Emotional/Neutral), *Region* (Anterior/Posterior), and *Laterality* (Left, Right) as repeated-measures factors. The factors *Region* and *Laterality* comprised the following subgroups of electrodes: anterior–left: AF3, F5, F3, F1, FC5, FC3, FC1; anterior–right: AF4, F6, F4, F2, FC6, FC4, FC2; posterior–left: CP5, CP3, CP1, P5, P3, P1, PO3; posterior–right: CP6, CP4, CP2, P6, P4, P2, PO4. The average potential of electrodes in these subgroups rather than their individual potentials was used for statistical analysis.

Results

ERPs

The ERPs elicited by touch and no-touch trials are presented in Figures 2 and 3. Analysis of N100 amplitudes revealed a significant *Touch* main effect, $F(1, 23) = 7.29$, $p < .05$, $h_p^2 = .24$, indicating that the N100 was larger during touch as compared to no-touch trials. A significant interaction of *Touch*, *Hemisphere*, and *Region*, $F(1, 23) = 5.55$, $p < .05$, $h_p^2 = .19$, suggested that the effect was differently distributed across the scalp. Follow-up analyses for each *Region* indicated that the *Touch* by *Hemisphere* interaction was significant over posterior, $F(1, 23) = 4.66$, $p < .05$, but not anterior sites, $p > .1$. Moreover, over posterior regions, the effect was larger over the right, $F(1, 23) = 11.5$, $p < .01$, as compared to the left hemisphere, $F(1, 23) = 4.67$, $p < .05$; see Figure 4.

Analysis of the P200 revealed a *Touch* by *Block* interaction, $F(2, 46) = 6.55$, $p < .01$, $h_p^2 = .22$. Follow-up analyses indicated that the P200 was larger on

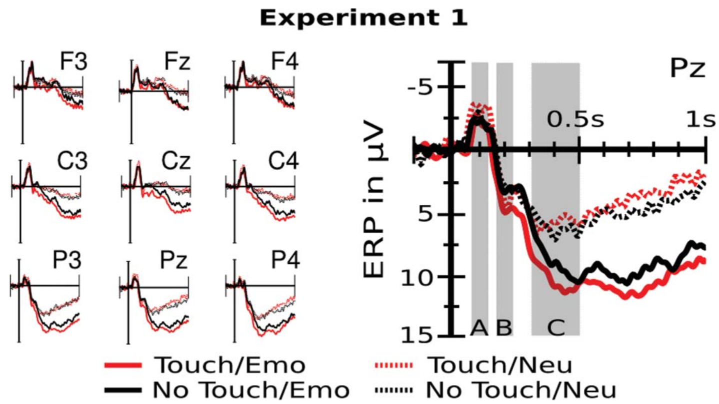

Figure 2. ERP time courses time-locked to picture onset. Emotional pictures are represented by solid lines; neutral pictures are represented by dotted lines. The shaded areas mark the statistical time window for (A) N100, (B) P200, and (C) LPC.

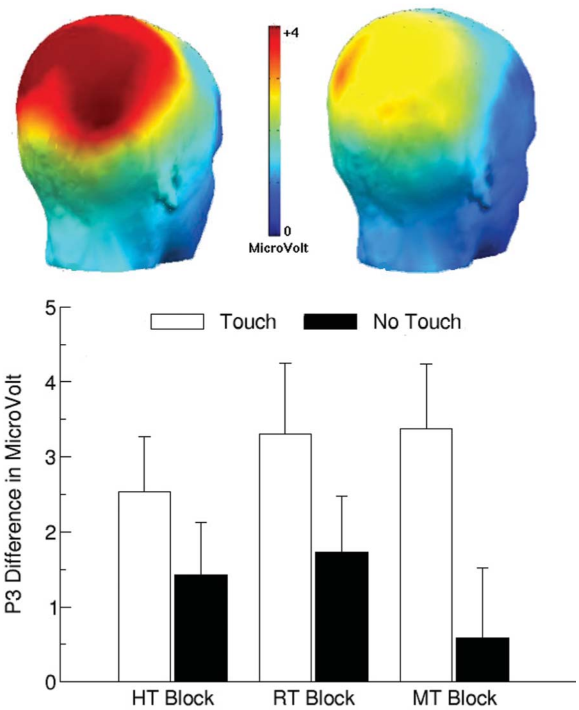

Figure 3. Illustrated is the LPC effect in Experiment 1. (Top) The difference maps derived by subtracting the late positivity (i.e., 300 to 500 ms following picture onset) in the neutral picture condition from the emotional picture condition for touch (left) and no-touch (right) trials. (Bottom) The mean ERP differences between the neutral and the emotional picture condition for the human touch (HT), the remote touch (RT), and the mechanical touch (MT) blocks. The error bars give the standard deviations of these differences.

touch as compared to no-touch trials in the RT, $F(1, 23) = 6.87$, $p < .05$, and tendentially in the HT block, $F(1, 23) = 3.26$, $p = .08$. No difference in P200 amplitude was observed in the MT block ($p > .1$). Additionally, there was an *Emotion* by *Block* interaction, $F(2, 46) = 3.59$, $p < .05$, $h_p^2 = .13$, indicating that emotional pictures elicited a greater P200 as compared to neutral pictures during the HT block, $F(1, 23) = 4.25$, $p = .05$. This effect was absent in the RT and MT blocks (p values > .1).

Analysis of the late positivity revealed a significant *Emotion* effect, $F(1, 23) = 29.66$, $p < .0001$, $h_p^2 = .56$, indicating that emotional pictures elicited a greater positivity than neutral pictures. An interaction between *Emotion* and *Region*, $F(1, 23) = 38.38$, $p < .0001$, $h_p^2 = .62$, suggested that this effect was stronger over posterior, $F(1, 23) = 61.05$, $p < .0001$, as compared to anterior regions, $F(1, 23) = 4.82$, $p < .05$. More importantly, however, the *Touch* by *Emotion* interaction, $F(1, 23) = 8.61$, $p < .01$, $h_p^2 = .27$, was significant without being further qualified by *Block*, $F(2, 46) = .44$, $p = .64$, $h_p^2 = .02$. Follow-up analysis of this interaction indicated that the *Emotion* effect was significantly larger when participants were touched, $F(1, 23) = 51.87$, $p < .001$, $h_p^2 = .69$) as compared to when they were not touched, $F(1, 23) = 4.77$, $p < .05$, $h_p^2 =.17$; see Figure 5. All other effects were nonsignificant, p values > .1.

Memory

Due to technical problems, the memory data from four participants were lost. The average discrimination sensitivity of the remaining participants was d' 3.07 (*SD* 1.6). An ANOVA with *Emotion*, *Touch*, and *Block* as repeated-measures factors revealed an Emotion main effect, $F(1, 19) = 6.42$, $p < .05$, suggesting that emotional images (mean 3.38, *SD* 1.5) were better remembered than neutral images (mean 2.77, *SD* 1.7). All other effects were nonsignificant (p values >.1).

Discussion

With the present study, we sought to determine whether touch influences ongoing information processing in a bottom-up or a top-down manner. Additionally, we were interested in identifying which aspects of information processing are subject to tactile influences. We found that touch, regardless of whether attributed to a friend or an inanimate object, modulates ERP correlates of picture processing. Thus, one may infer that this modulation occurred in a bottom-up manner. Additionally, the ERP revealed an effect of touch on early perceptual and late reflective processes. Contrary to our expectation, however, touch enhanced early perceptual processes regardless of picture valence. Moreover, the LPC difference normally observed between emotional and neutral items was increased rather than decreased by touch.

Given these findings, one may venture that touch regardless of attribution served as an attentional cue. Moreover, due to the way in which touch and picture presentations were paired, this cueing may not have been touch-specific but simply reflect participants using the touch to predict picture presentation. Touch, by always preceding a picture, may have prepared participants for visual processing. Such preparation may have been absent during no-touch trials, accounting for the observed effects. We addressed this possibility in a second experiment. Here, touch presentation was fully crossed with picture presentation such that pictures occurred with and without touch and touch occurred with and without pictures. Thus, touch no longer predicted the presentation of a picture. If the findings observed in Experiment 1 resulted merely from the predictive quality of touch, they should no longer be present in Experiment 2.

EXPERIMENT 2

Methods

Participants

Twenty-four female participants that had not participated in Experiment 1 and their same-sex platonic friends were invited to this study. The data from one participant were excluded due to excessive movement artifacts. The remaining participants were on average 21.26 years old (*SD* 1.51) and their friendships ranged in duration from 3 months to 9 years (mean 2.98, *SD* 2.66). The work reported here was approved by the Institutional Review Board of the National University of Singapore and concords with the 1975/1983 Helsinki Declaration on human subject rights. Accordingly, all participants and friends gave informed consent prior to the experiment.

Materials and design

The stimulus material was identical to that used in Experiment 1.

The design differed from Experiment 1 in two ways. First, we changed the type of trials presented to the participants (Figure 4). Again a trial started with a fixation cross. On half the trials, this cross remained on the screen for 2500 ms. For the remainder of the trials it lasted for only 500 ms and was replaced by a picture that lasted for 2000 ms. The interval between trials was blank and ranged from 3 to 5 s plus the time friends took to administer and remove touch. As in the preceding experiment, friends were cued to touch by a tone delivered through headphones. Touch trials started 1 s after touch was established. The signal to remove touch coincided with fixation offset or picture offset. On no-touch trials, an average touch duration was added to the 3 to 5 s ITI range. This duration was derived from 15 touch practice trials at the beginning of the experiment. In all, participants completed 120 touch trials of which 30 entailed a neutral picture, 30 entailed an emotional picture, and 60 entailed fixation only. Additionally, they completed 120 no-touch trials, 30 of which entailed a neutral picture, 30 an emotional picture, and 60 with fixation only. Due to the necessary increase in total trial numbers per touch condition, this experiment comprised only one block and only direct touch from the friend was explored.

The remaining methodological details of Experiment 2 were comparable to Experiment 1.

Results

ERPs

The ERPs elicited by touch and no-touch trials are presented in Figure 5. Analysis of N100 amplitudes revealed an interaction of *Emotion* and *Region*, $F(1, 22) = 4.97$, $p < .05$, $h_p^2 = .18$, and an interaction of *Touch* and *Region*, $F(1, 22) = 14.86$, $p < .001$, $h_p^2 = .4$). Both emotional pictures, $F(1, 22) = 4.98$, $p < .05$, and pictures presented in the context of touch, $F(1, 22) = 8.95$, $p < .01$, elicited a larger N100 over posterior, but not anterior (p values > .1), sites.

In the P200 time window, we observed a *Touch* by *Region* interaction only, $F(1, 22) = 10.16$, $p < .01$, h_p^2

= .33. Touch enhanced P200 amplitudes over anterior, $F(1, 22) = 5.45$, $p < .05$, but not posterior sites ($p > .1$).

Analysis of the LPC revealed again an *Emotion* effect, $F(1, 22) = 11.47$, $p < .01$, $h_p^2 = .34$, indicating greater LPC amplitudes to emotional as compared to neutral pictures. A significant *Emotion* by *Region* interaction, $F(1, 22) = 8.19$, $p < .01$, $h_p^2 = .27$, demonstrated that LPC differences between emotional and neutral pictures were smaller over anterior, $F(1, 22) = 5.63$, $p < .05$, as compared to posterior sites, $F(1, 22) = 17.68$, $p < .001$. The *Emotion* effect was also qualified by *Touch*, $F(1, 22) = 6.85$, $p < .05$, $h_p^2 = .24$). The *Emotion* main effect was significant on touch, $F(1, 22) = 25.3$, $p < .0001$, but not no-touch trials, $p > .1$. All other effects were nonsignificant (p values > .1).

Memory

The analysis of picture recognition revealed no significant effects (p values >.1). In general, participants performed at ceiling (mean d' 3.5, SD 1.4). Please note that fewer pictures than in Experiment 1 were presented and that the pictures were presented at a slower rate. This may explain the ceiling effect.

Discussion

While the early effects of emotion differed slightly between Experiment 1 and 2, the touch effects were essentially identical. In both experiments, touch enhanced N100 and P200 amplitudes. But more importantly, touch interacted with emotion in the LPC. Touch enhanced the LPC difference between emotional and neutral pictures both when it predicted the presentation of a picture (Experiment 1) and when it was not predictive (Experiment 2). However, before concluding on the relationship between touch and emotional processing we sought to further probe whether the effects of touch on picture processing observed in Experiments 1 and 2 are touch-specific. Existing evidence on cross-modal enhancement of

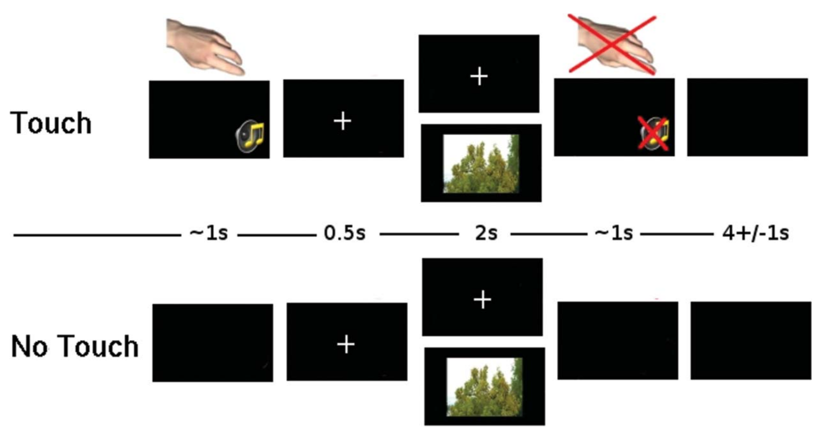

Figure 4. The events unfolding during touch and no-touch trials in Experiment 2.

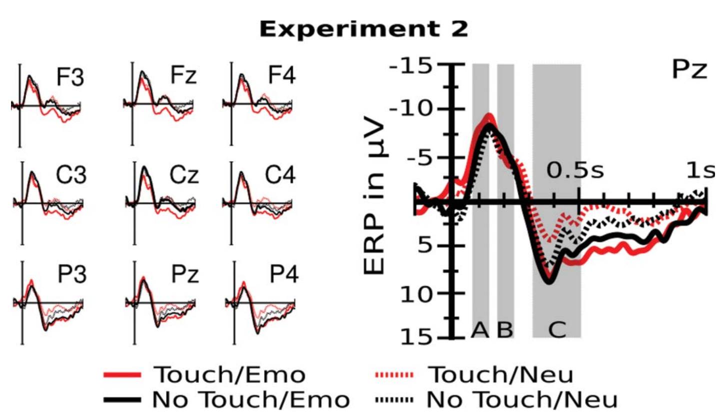

Figure 5. ERP time courses time-locked to picture onset. Emotional pictures are represented by solid lines; neutral pictures are represented by dotted lines. The shaded areas mark the statistical time window for (A) N100, (B) P200, and (C) LPC.

perceptual processes raises the possibility that they are not. In particular, researchers have observed that a task-irrelevant and nonpredictive auditory signal facilitates attention to a visual target stimulus (Eimer, Van Velzen, & Driver, 2005; McDonald, Teder-Sälejärvi, Di Russo, & Hillyard, 2005; McDonald, Teder-Sälejärvi, & Hillyard, 2000). Moreover, as in the present study, this facilitation is accompanied by an increase in N100 amplitude. Thus, one may venture that the cross-modal integration of sensory cues and emotional events is modality-unspecific. If true, then a tone should modulate N100, P200, and the LPC emotion effect in a similar way as touch did in Experiments 1 and 2. If, however, this modulation is touch-specific it should be absent when touch is replaced by a tone. Experiment 3 was conducted to decide between these possibilities.

EXPERIMENT 3

Methods

Participants

Twenty-four female participants were invited to this study. They were on average 21.8 years old (*SD* 1.6). The work reported here was approved by the Institutional Review Board of the National University of Singapore and concords with the 1975/1983 Helsinki Declaration on human subject rights. Accordingly, all participants and friends gave informed consent prior to the experiment.

Materials and procedures

This experiment was identical to Experiment 2, except that a 300 Hz tone replaced the tactile contact. The tone was played for the same duration for which touch was provided in Experiment 2.

Results

Event-related potentials

Figure 6 illustrates the ERP results. In the N100 time window, we observed a marginal main effect of *Tone*, $F(1, 23) = 3.85$, $p = .06$, $h_p^2 = .14$, and a *Tone* by *Region* interaction, $F(1, 23) = 28.93$, $p < .0001$, $h_p^2 = .56$. Over anterior sites, the N100 was smaller when pictures were accompanied by a tone as compared to when they were presented without a tone, $F(1, 23) = 23.01$, $p < .0001$. This effect was nonsignificant over posterior sites, $p > .1$.

An effect of *Tone*, $F(1, 23) = 9.36$, $p < .01$, $h_p^2 = .29$, and an interaction between *Tone* and *Region*, $F(1, 23) = 8.99$, $p < .01$, $h_p^2 = .28$, were also observed in the P200 time window. Pictures elicited a larger P200 when they were accompanied by a tone as compared to when they were presented without tone. This effect was more pronounced over anterior, $F(1, 23) = 14.32$, $p < .001$, as compared to posterior sites, $F(1, 23) = 4.96$, $p < .05$. A significant *Emotion* main effect indicated that P200 amplitudes were larger for neutral as compared to emotional pictures, $F(1, 23) = 6.15$, $p < .05$, $h_p^2 = .21$.

In the LPC range, the *Tone* by *Region* interaction was again significant, $F(1, 23) = 5.63$, $p < .05$, $h_p^2 = .19$, indicating that LPC amplitudes tended to be larger for tone as compared to no-tone trials over anterior, $F(1, 23) = 3.29$, $p = .08$, but not posterior regions, $p > .1$. A significant *Emotion* by *Region* interaction, $F(1, 23) = 17.08$, $p < .001$, $h_p^2 = .43$, revealed that the LPC was larger for emotional as compared to neutral pictures

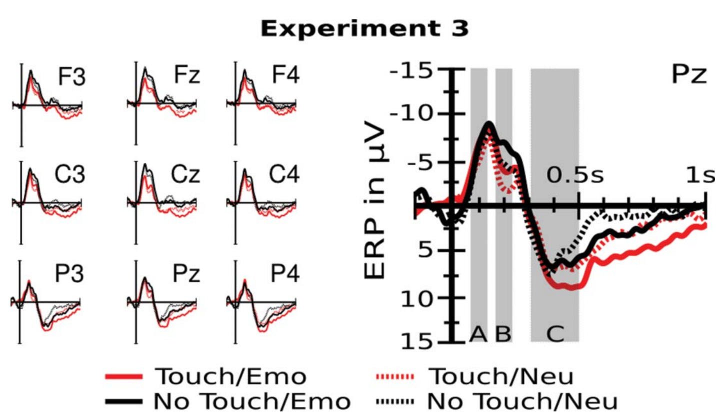

Figure 6. ERP time courses time-locked to picture onset. Emotional pictures are represented by solid lines; neutral pictures are presented by dotted lines. The shaded areas mark the statistical time window for (A) N100, (B) P200, and (C) LPC.

over posterior, $F(1, 23) = 4.92$, $p < .05$, but not anterior sites, $p > .1$. Importantly, the *Emotion* effect was not qualified by the presence or absence of a tone ($p > .1$). All other effects were nonsignificant (p values $> .1$).

Memory

The analysis of picture recognition revealed a significant main effect of Tone, $F(1, 23) = 7.5$, $p < .05$, indicating that participants were more likely to remember a picture if it was studied together with a tone (mean d' 3.47, *SD* 1.12) as compared to without a tone (mean d' 3.14, *SD* 1). No other effects reached significance (p values $> .1$). Please note that on average performance was poorer than in Experiment 2, suggesting that the stimulus context (friend touch vs. tone) influenced memory processes.

GENERAL DISCUSSION

The present study explored the influence of touch on the processing of concurrently presented information. Experiment 1 revealed that touch, regardless of attribution, facilitates early perceptual and late emotion discrimination processes in the visual modality. Experiment 2 replicated these results while controlling for the predictive quality of touch. Experiment 3 was aimed at specifying whether a nonsocial auditory signal, such as a simple tone, would likewise facilitate visual processing. The results from this last experiment point to both modality-unspecific and touch-specific facilitation effects. We discuss the implications of these results and directions for future work below.

Tactile facilitation of early visual processing

We investigated the influence of touch on early visual processing by examining two ERP components previously associated with attention to and emotional evaluation of visual stimuli (for a review see Olofsson et al., 2008). The first component of interest was the N100, a negativity peaking around 100 ms following stimulus onset. Typically, N100 amplitudes are larger for attended as compared to unattended stimuli, suggesting that they reflect the allocation of attentional resources to stimulus perception (Hermann & Knight, 2001). Moreover, this effect appears to be modality-specific. A more frontal N100 modulation as a function of attention is observed in the auditory modality, whereas a more posterior modulation is observed in the visual modality (Hermann & Knight, 2001). In the present study, the posterior N100 was significantly larger for pictures preceded by touch as compared to pictures presented without touch. When pictures were preceded by a tone, the frontal N100 was reduced relative to pictures presented without a tone. Together this indicates that touch but not tone facilitated early visual processing. Moreover, the tone reduced frontal aspects of the N100, suggesting that its continuous presentation inhibited amodal attentional processes presumably supported by frontal lobe regions (Hermann & Knight, 2001).

The latter finding may appear in conflict with research that demonstrated cross-modal attentional facilitation from the auditory to the visual modality. In previous studies, researchers observed that an unpredictive auditory signal facilitated rather than inhibited visual attention. One critical difference between that work and the present study is that the former leveraged on the spatial relationship between an auditory signal and a visual target. That is, facilitation was observed if both occurred in the same spatial location (e.g., same hemifield) relative to when they occurred at opposite locations (Eimer et al., 2005; McDonald et al., 2000, 2005). In the present study, the tone was presented over headphones and thus created the impression of arising from the centre of the listener. As such, the sound source was spatially segregated from that of the pictures displayed in front of the participant. Therefore, it may have failed to facilitate early visual processing. Importantly, touch was likewise segregated from the picture. That it nevertheless enhanced the N100 suggests that tactile influences on this component may be more spatially distributed than those of auditory signals. Moreover, the gentle touch investigated here may play a greater role than other sensory signals in increasing general (as opposed to focused) awareness.

A second ERP component of interest was the P200. Like the N100, this component has been implicated in early sensory processing. The amplitude of the P200 correlates positively with sensory salience. For example, loud sounds elicit a larger P200 than soft sounds (Beauducel et al., 2000). Moreover, emotional stimuli have been shown to elicit a larger P200 than neutral stimuli (Kiss & Eimer, 2008; Paulman & Kotz, 2008). Unlike the N100, however, the P200 is typically reduced rather than increased for stimuli whose spatial location has been cued (Eimer et al., 2005; McDonald et al., 2000, 2005). In the present study, pictures presented in the context of touch that was attributed to a friend elicited greater P200 amplitudes than pictures presented without touch. Tones preceding a picture had a similar effect, suggesting that both interpersonal touch and tone cues enhanced the sensory salience or emotional significance of accompanying pictures.

Support for this proposition comes from previous work that not only found larger P200 amplitudes for emotional as compared to neutral stimuli, but also revealed that the emotional significance of a stimulus and its context are integrated in the P200 time range. For example, happy music was found to enhance the P200 amplitude for positive relative to neutral or negative pictures (Spreckelmeyer, Kutas, Urbach, Altenmueller, & Muente, 2006). Words following a sentence spoken in a happy voice elicited a larger P200 when they were positive as compared to negative (Schirmer, Kotz, & Friederici, 2005). Additionally, the congruity between facial and vocal information modulated P200 amplitude (Pourtois, Debatisse, Despland, & de Gelder, 2002; Pourtois, de Gelder, Vroomen, Rossion, & Crommelinck, 2000). Together this evidence suggests that emotional context potentially enhances the sensory salience or emotional significance of a stimulus in the P200 time range. In line with this and our present findings, one may speculate that sensory cues, regardless of modality, act in a similar way. Specifically, they might be alerting and enhance sensory processing or perceived emotionality of concurrently presented information. However, given that in the present study, the P200 touch effect showed for socially attributed touch only, it is possible the touch and the tone effect qualitatively differ. Specifically, the tone effect may simply be an extension of the observed N100 suppression and reflect the role of tone in modulating spatially focused attention.

Tactile facilitation of emotion discrimination

ERP markers for emotion discrimination have been reported as early as 100 ms following stimulus onset. In line with this, we found the emotional content of images to modulate N100 and P200 amplitudes. That these effects were not consistent across the three experiments accords with a recent review by Olofsson and colleagues (2008) who also found them "inconsistently reported." Moreover, the close overlap of different sensory, cognitive, and emotional processes in this time range makes the identification and characterization of emotion-related ERP components difficult. More promising is a late positive deflection that reliably shows an increased amplitude to emotionally arousing as compared to neutral stimuli (Olofsson et al., 2008). This effect, typically larger over posterior than anterior regions, was replicated in the three experiments presented here. Additionally, it was reliably modulated by a picture's tactile context. Touch, regardless of source and attribution, enhanced the LPC emotion effect without changing its distribution (i.e., the *Touch* × *Emotion* × *Reg*ion interaction was nonsignificant). The absence of distributional changes on touch trials suggests that touch amplified existing stimulus processing without modifying this processing in a qualitative way. Moreover, given the lack of block differences in Experiment 1, it seems that this amplification arose in a bottom-up manner possibly supported by subcortical structures seated deep within the brain (e.g., thalamus, amygdala). Given that both tactile and emotional processing has been linked to such structures (Morris, Oehman, & Dolan, 1999; Olausson et al., 2010; Vuilleumier, Armony, Driver, & Dolan, 2003), this conclusion is neuroanatomically plausible.

Together, our findings suggest that touch enhances stimulus evaluation processes associated with the late positivity. Emotional information presented concurrently with touch may be more motivating such that more processing resources are allocated to them than to emotional information presented without touch. Given the use of emotionally negative images, an enhanced response in the context of touch may be surprising. It seemingly conflicts with the notion that touch relaxes, reduces stress, and blunts an individual's response to negative events (for a review see Gallace & Spence, 2008). Moreover, observations of touch enhancing positive attitude and prosocial behaviour have nurtured the idea that touch positively biases an individual's emotional equilibrium. However, rather than simply being a positive stimulus, touch is a complex social signal that likely evolved for its potential to influence and coordinate the behaviour of social animals (Dunbar, 2008). One such influence may be the facilitation of cooperative behavior in the touched individual (e.g., Fisher, Rytting & Heslin, 1976). Based on the present findings, we propose that such behavior occurs because the tactile signal alerts its recipient and enhances the processing of concurrent events, particularly if they are emotional. Such enhanced processing may then, among others, boost empathy and increase the likelihood that the touch recipient acts in favour of the toucher.

On the nature of tactile effects

Compared to other species, primates invest substantial time in social grooming or touch. The time spent on this activity surpasses a necessary investment in hygiene and increases proportionally with group size (Dunbar, 2008). Therefore, researchers have speculated that tactile contact serves an important social function (Dunbar, 2008). Evidence of touch propagating well-being and prosocial behaviour confirmed these speculations and implicated both short- and long-term mechanisms. While long-term mechanisms likely involve changes in the oxytocin system (Gallace & Spence, 2008), the mechanisms underlying short-term tactile effects are as yet poorly understood. Based on research on the role of tactile partners and social support, one may speculate that the cognizance of touch is critical. Moreover, knowing that a trusted person is close may influence the interpretation of tactile experience and be responsible for its influence on concurrent information processing.

In contrast to such speculations, however, the present results suggest that attributional processes play a subordinate role. Only the P200 effect depended on touch attribution. Physical closeness or touch attribution played no role for the N100 and the LPC. Thus, one may conclude that the short-term effects of gentle touch arise primarily from bottom-up processing of somatosensory information. In line with this, there are a number of other studies that imply bottom-up processing of social signals (Frith & Frith, 2008; Morris et al., 1999; Schirmer, Kotz, & Friederici, 2005; Vuilleumier et al., 2001). For example, physiological responses to negative facial expressions have been found with subliminal exposures or when the faces were unattended (Morris et al., 1999; Vuilleumier et al., 2001). FMRI research has linked these bottom-up effects to a processing pathway extending from the thalamus to the amygdala and bypassing cortical areas (Morris et al., 1999; Vuilleumier et al., 2003). For touch, a similar pathway, directly linking somatosensory stimulation to structures implicated in emotion and social perception, has been identified (Olausson et al., 2002; McGlone, Vallbo, Olausson, Loken, & Wessberg, 2007). As this pathway is activated by a specific mechanical stimulation regardless of whether human- or nonhuman-generated, it offers a neuroanatomical substrate for bottom-up tactile influences on concurrent mental processes.

CONCLUSIONS

The present study identified several ways in which tactile stimulation of the skin influences the processing of concurrently presented information. However, before concluding on the significance of these influences, we would like to highlight two potential shortcomings of our work. First, we investigated the processing of touch in an exclusively female sample. Given existing sex differences in social/emotional perception (e.g., Schirmer, Escoffier, & Simpson, 2007) and tactile behavior (e.g., Remland & Jones, 1988; Willis & Rawdon, 1994), it is possible that the observed tactile effects would qualitatively and/or quantitatively differ between women and men. Second, we observed tactile influences to differ from those of other sensory cues (e.g., tones), suggesting that they reflect a special kind of signal. One may object that in the present study touch and tone were not matched for their perceived intensity and that this offers an alternative account. Specifically, the touch may have been perceived as a stronger sensory cue than the tone, and increasing tone amplitude could have resulted in similar effects. We would like to counter that touch and tone effects were qualitatively different. In the N100 time range, opposite effects emerged and for the LPC, only touch but not tone modulated the emotion effect. Thus, we believe that simply increasing tone amplitude would be unlikely to produce the ERP patterns observed for touch. However, to fully dispel this concern future research needs to compare touch and tone processing within the same individuals and equate their perceived intensity.

Despite these limitations, the present study offers important insights into the processing of touch. Although closeness to a friend can influence the processing of emotionally arousing events, we show that touch, regardless of source and attribution, outweighs these effects. Moreover, enhanced perceptual processing and emotion discrimination can be seen regardless of whether the touch is performed by a friend or a mechanical device, but not when touch is replaced by a different modality cue. As such, the present findings mark touch as a social signal that can be processed implicitly and that can bias prosocial behaviour in the absence of conscious reflection (Frith & Frith, 2008).

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