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Mirror-touch experiences in the infant brain

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ABSTRACT

Several adult studies have proved the existence of a shared neural circuit in the somatosensory cortices that responds to both the body being touched and the sight of the body being touched. Despite the fundamental role of touch in infancy, the existence of similar visuo-tactile mirroring processes, supporting both felt and seen touch, still needs an in-depth empirical investigation. To this aim, we explored 8-month-olds mu desynchronization over somatosensory sites in response to felt and observed touch in a live experimental setting. EEG desynchronization (6–8 Hz mu frequency range) was measured during three experimental conditions: i) infants were stroked on their right hand by a parent (Touch condition); ii) infants observed a right hand being stroked (Observation Touch condition); iii) infants observed a right hand moving over the left hand without making contact (Action Control condition). Mu desynchronization of somatosensory sites contralateral to the hand being stroked emerged in response to both Touch and Observation Touch conditions, but not in the Action control condition. Further, greater mu desynchronization was found in the Touch and Observation Touch conditions as compared to the Action control condition. Our results highlight the early involvement of a shared somatosensory system, likely supporting infants' understanding of others' tactile sensations.

Introduction

Interpersonal touch is a fundamental source of sensory and affective information early in life, being one of the very first sensory modality to develop in the womb (Hepper, 2008). Studies have indeed shown that fetuses are active explorers of their own body and the surrounding uterine environment (Sparling et al., 1999) and respond to touch performed by the mothers on their abdomen by increasing their body movements (Marx & Nagy, 2015). This early tactile experience suggests that the somatosensory system may already be responsive to tactile stimulations since birth, as suggested by brain responses detected already in preterm newborns (Nevalainen et al., 2014). Furthermore, infants as young as 60 days of age respond to tactile stimulations delivered to different body-parts (i.e., foot, hand, and lips, see Meltzoff et al., 2019; Saby et al., 2015) and newborns visually recognize hand-to-hand tactile gestures (Addabbo et al., 2015), both contributing to the notion that responses to bodily-related stimuli may support the emergence of an early sense of self and promote social cognition (Meltzoff et al., 2019; Saby et al., 2015).

Evidence in adults indicates that the somatosensory cortical system may process information beyond somatosensation, being involved in a visual, mirror-like encoding of others' tactile experiences. This putative visuo-tactile mirror system seems to exist in the human brain and comprises somatosensory areas that respond to both the body being touched and the sight of the body being touched (i.e., Bolognini et al., 2014; Keysers et al., 2010; Pihko et al., 2010), being also endorsed with mechanisms distinguishing own from others' somatosensations (Pisoni et al., 2018). The involvement of the somatosensory system during touch observation is also documented in electroencephalographic (EEG) studies showing attenuation of the mu rhythm both when receiving (Cheyne et al., 2003; Singh et al., 2014; Valenza et al., 2018; Pisoni et al., 2018) and observing a tactile stimulation (Peled-Avron et al., 2016; Perry et al., 2010; Schirmer & McGlone, 2019), suggesting that mu rhythm suppression could be related to somatosensory resonance (Coll et al., 2015). Such vicarious somatosensory activity is suggested to be at the roots of our empathic understanding of others' emotional and mental states (Bolognini et al., 2013; Schaefer et al., 2012), and it may support social understanding and interpersonal communication conveyed by touch (Gallace & Spence, 2010).

Because touch is charged with a particularly strong social and affective meaning early in development (Field, 2002), it could be hypothesized that shared

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somatosensory activation supporting felt and observed touch may represent a property of the developing brain. To date, there is converging evidence documenting the involvement of the sensorimotor system during infants' observation of others' actions (for a review, see Marshall & Meltzoff, 2014; Quadrelli & Turati, 2016). Particularly, suppression of the mu rhythm, a specific EEG frequency band in the alpha frequency range (i.e., □8–13 Hz in adults and □6–9 Hz in infants; Marshall et al., 2002) recorded over sensorimotor sites, has been used to infer mirror system activity in human adults (see Fox et al., 2016 for a meta-analysis). Such desynchronization has been observed when the infant both performs and observes an action (Marshall & Meltzoff, 2011; Marshall et al., 2011), and extends to actions that are not seen but heard (Quadrelli et al., 2019a). These findings suggest that a shared mechanism that matches the motor representations of an action to its corresponding visual or auditory representation is functional from early in development (Marshall et al., 2011; Quadrelli et al., 2019a).

Recently, a few studies have attempted to investigate whether infants share others' tactile sensation, and two recent EEG/ERP studies have provided evidence that infants' somatosensory responses to a vibrotactile stimulation are modulated by the sight of touches delivered to another person (Drew et al., 2018; Rigato et al., 2019). Specifically, Drew et al. (2018) showed infants with a live-hand or foot being touched, while the infant received brief mechanical tactile stimuli to the same or different body part. Results showed that congruency effects (i.e., seen and felt touch on the same body part) were observed in the beta rhythm (11–13 Hz) and in the late potential of the somatosensory evoked responses (SEP). Interestingly, mu suppression (6–9 Hz) was found irrespective of body visuo-tactile congruency and showed a somatotopic pattern of activation. So far, only one Magnetoencephalography (MEG) study directly compared somatosensory activity following felt and observed touch in infancy. This study has shown that felt and observed object-to-hand touches on the hand and foot partially engage overlapping somatosensory areas in 7-month-olds (Meltzoff et al., 2018). However, it is not clear whether infants' less consistent somatosensory activation during touch observation reflected a specific response to the sensory consequence generated by the contact of the object on the body part, or an unspecific visual response to the motion of the object toward and away from the body. Without a control condition disentangling between these two alternative interpretations, firm conclusions on the neural linkage between self-other bodily sensory experiences in infancy cannot be drawn.

Moreover, there is little evidence of mu desynchronization in response to both felt and observed touch in infancy, which would provide a window into potential mirroring mechanisms in the processing of seen and felt tactile experiences. To date, only one study has investigated mu rhythm modulations during the observation of touch in infancy. Müller et al. (2017) found that mu rhythm desynchronization in centro-parietal sites differentiates between the observation of tactile stimulations of human vs. non-human body parts (Müller et al., 2017). However, this study lacks a direct comparison with a felt touch condition, leaving unsolved the issue of whether the mu rhythm attenuation reflected a specific mirror response to others' sensory experience. Overall, to date, no study directly compared infants' mu rhythm suppression in response to felt and observed tactile stimulations. Further, no study recorded such neural responses during real-life events. Indeed, studies with infants have shown that live observations are more effective than videos in activating the sensorimotor cortex in response to observed actions (for a review, see Cuevas et al., 2014).

Here, we explored 8-month-olds mu rhythm desynchronization in somatosensory sites in response to felt and observed touch during real-life tactile experiences. We measured EEG desynchronization in the 6–8 Hz mu frequency range over centro-parietal electrodes (CP3, CP4) in three independent groups of 8-month-old infants, each assigned to one of three experimental conditions. In the first condition, infants were stroked on their right hand by their parent (Touch condition); in the second condition, infants observed a human right hand of a live model being stroked by the left hand of the same individual (Observation Touch condition); in the third condition, infants observed a human left hand approaching the right hand without touching it (Action Control condition). We expected infants to be able to match self to others' bodily sensations and to exhibit mu rhythm suppression in overlapping somatosensory sites both when they were stroked and when they observed others being stroked. Further, we expect differential mu rhythm activation in the Action control condition compared to the Touch and Observation touch condition, thus showing the specificity of such somatosensory response to the sensory experience generated by the felt/observed tactile contact.

Methods

Participants

We recruited 102 8-month-old infants from a diverse urban environment, including the metropolitan and

suburban areas of Milan (Italy). All infants were born at term (37–42 weeks gestation), had a normal birth weight (>2500 g), did not suffer from any neurological or other medical conditions, and had normal vision and hearing for their age. The final sample consisted of forty-five 8-month-old infants (22 females, mean age = 259 days; range 231–274 days), evenly allocated to the three experimental conditions. Additional 57 infants were tested but excluded from the final analysis due to fussiness (n = 25) and/or excessive artifacts (n = 32). The sample size and proportion of excluded infants are similar to other EEG studies investigating mu rhythm with infants this age (e.g., Quadrelli et al., 2019b; Southgate & Begus, 2013). Furthermore, an a priori power analysis performed using GPower indicated that 42 participants would be needed in order to have 80% probability of detecting a significant two-way interaction (α =.05) with a medium effect size (r = .25) (Cohen, 1992) in a repeated-measures ANOVA. The study followed the ethical standards (the Declaration of Helsinki, BMJ 1991; 302:1194) and was approved by the ethical committee of the University of Milan-Bicocca (Protocol number: 236). Parents filled out a consent form for their infants' participation prior to the study.

Stimuli, apparatus and procedure

Testing took place in an electrically shielded room. Infants were seated on their parent's lap during the experimental session. A video-camera recorded a video of the infant, which was used for off-line coding of attention and body movements occurring during each trial. Infants were randomly assigned to one of three independent groups: *Touch condition, Observation Touch condition, and Action Control condition*(Figure1). In the *Touch condition*, the parent stroked the dorsal part of the infant's right hand, from the fingers to the wrist,

using four fingers. The parent always stroked the right hand of the infant. Parents were instructed to keep the duration of the stroke at approximately 1000 ms, and the interval between tactile stimulations around 3000 ms. During the stimulation, because infants were in a fully darkened room and had nothing to watch, we kept an abstract screensaver of a 24" monitor on, which was placed at about 80 cm in front of the infant. The screensaver used was the same for all infants. The choice of keeping the screensaver on was motivated by the fact that infants felt discomfort in complete darkness; furthermore, giving them something to watch kept them attentive for a longer period, allowing the parent to perform a higher number of tactile stimulations/trial.

Parents were trained on how to stroke their infant's right hand while keeping him/her on their lap, in order to keep stimulations and the testing procedure comparable across participants (despite the different agents performing the stroke). It is important to note that parents were asked not to deliver any tactile stimulation other than the experimental stroke. Trials in which the parent delivered extra tactile stimulation to the infant were excluded from the analysis.

In the *Observation Touch condition*, an experimenter sat behind a black curtain in the complete darkness, facing the caregiver and infant at a distance of about 50 cm. This was made to prevent infants from seeing anything but the hands of the experimenter, which were placed on a black table and illuminated by a cone of light coming from a lamp positioned above the table. During the interstimulus interval (approximately 3000 ms), only the right hand was visible to the infant from a third-person perspective and was placed with the palm on the table. When the stimulation started, the left hand of the experimenter appeared under the cone of light, and stroked the dorsal part of the right hand, from the fingers to the wrist (approximately 1000 ms in
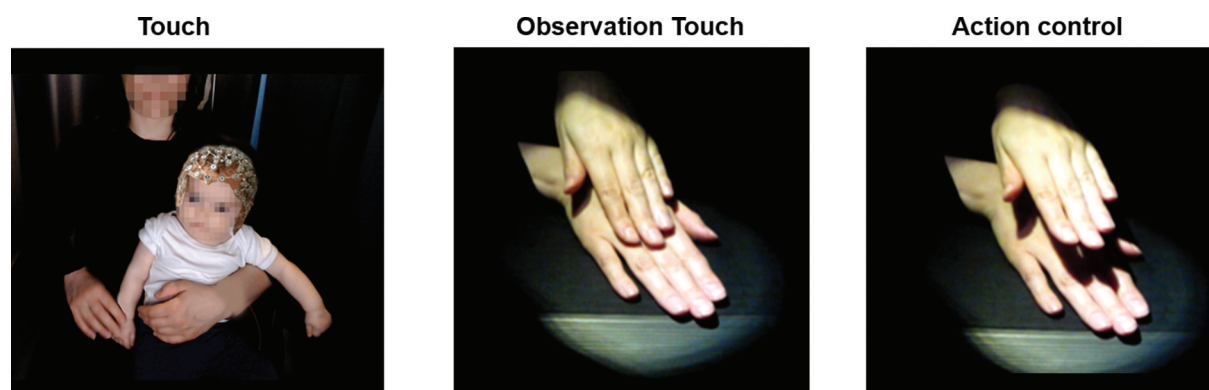
Touch	Observation Touch	Action control

Figure 1. Images showing the tactile stimulation preformed by the mother on the infants' hand during the touch condition (Left), and a frame of the live stimuli presented during the observation touch (Middle) and action control condition (Right).

duration), using four fingers. The experimenter moved away the left hand immediately after the stroke. In the *Action Control condition*, the infant observed the same action performed in the Observation Touch condition, with the only exception that this time, the left hand of the experimenter moved along the right hand, without making any contact. The kinematics of the no-contact stroke was kept similar to the real stroke delivered in the *Observation Touch condition*, precisely to control for the effects of the action itself (i.e., the hand approaching the other hand). Note that, both in the Observation Touch and Action Control conditions, the stroked hand (both of the infant and of the experimenter) was always the right one. Furthermore, it was always the same trained experimenter that performed the action in both Observation Touch and Action Control conditions, in order to maintain the types of actions as similar as possible. Stimuli were delivered/presented continuously until the infant became overly fussed or stopped paying attention to the stimuli.

Electroencephalogram collection and processing

EEG was recorded using a 128-electrode HydroCel Geodesic Sensor Net (Electrical Geodesic In., Eugene, OR) and sampled at 500 Hz by means of an EGI NetAmps 300 amplifier. The signal was recorded with respect to the vertex electrode and re-referenced to the average reference. A .1–100 Hz band-pass filter (.1 Highpass, 100 Hz Lowpass) was applied online, and impedances were checked prior to the beginning of each session and considered acceptable if lower than 50 KΩ. Markers defining the onset of the felt/observed tactile stimulations were added offline on the basis of the video recording of the infant, which was synchronized with the EEG signal. EEG data were further high-pass filtered offline (0.3 Hz) and segmented into 2400 ms epochs, beginning 1000 ms before and ending 1400 ms after stimulus onset. Trials were excluded if more than eighteen bad channels were detected. Of the remaining trials, individual bad channels were replaced using spherical spline interpolation. To ensure that we measured sensorimotor activation in response to the observation of movement rather than a consequence of the infant own concurrent movements, a careful double-step procedure for eliminating movement artifacts was adopted. First, all trials containing more than 15% of channels with signals exceeding ± 200 μV were detected and excluded via an automated algorithm. Second, video-recordings of the infants, obtained through the infrared camera hidden over the monitor, were coded offline independently from the automated artifact detection procedure and served to exclude from analysis all trials presenting any gross or fine movements not

automatically detected, or trials in which the infant did not attend to the screen. After the artifact rejection procedure, the mean number of artifact-free trials per infant contributing to analyses was 12.13 (Touch: M = 8.13, SD = 2.85; Observation Touch: M = 14.13, SD = 5.60; Action Control Condition: M = 14.13, SD = 5.73). In general, infants included in the Touch condition contributed to less artifact-free trials compared to infants included in both the Observation Touch, $t(28) = -3.70$, $p < .001$, $d = 1.35$, and the Action Control condition, $t(28) = -3.63$, $p = .001$, $d = 1.33$, conditions, while importantly no difference was observed between the two observation conditions, $t(28) = 0.00$, $p = 1.00$, $d = .00$.

Time-frequency analyses were performed on each artifact-free trial using continuous wavelet transform with Morlet wavelets at 1 Hz intervals in the 3 to 20 Hz range. After similar studies investigating mu rhythm band modulation (e.g., De Klerk et al., 2015; Pomiechowska & Csibra, 2017) or performing time-frequency analysis to uncover other stimulus-induced oscillatory responses in infancy (e.g., Csibra et al., 2000; Parise & Csibra, 2013), we calculated the absolute value (i.e., the amplitude, not the power) of the resulting complex coefficients. In order to eliminate distortions created by the wavelet transform, the first and the last 400 ms of each trial epoch were removed, and a 500 ms baseline period starting 600 ms before stimulus onset was selected. We identified a 3-Hz-wide frequency band (6–8 Hz) that best reflected activity of the somatosensory cortex during the experimental condition during which infants effectively experienced touch. Selection of such frequency band was motivated by previous work showing that in infants of this age, the most reactive frequency band to movement observation is the 6–8 Hz band (Marshall & Meltzoff, 2011; Marshall et al., 2002). Furthermore, visual inspection of our data in the Touch condition confirmed that activation elicited by the sensory stimulation reached its peak across participants within this frequency band. Baseline correction was performed at each frequency within the 6–8 Hz range by subtracting the mean activity of the 500 ms baseline period from the signal recorded during the whole stimulus presentation period. Average wavelet coefficients within infants were calculated by taking the mean across the trials. As in previous studies investigating mu band modulation in infancy (De Klerk et al., 2015; Quadrelli et al., 2019b; Saby et al., 2012), activity over a cluster of electrodes disposed over the left (42, 47, 51, 52 and 59), and right hemispheres (91, 92, 93, 97 and 98) was analyzed. The scalp locations of these left and right electrode clusters correspond to the locations of Cp3 and Cp4 in the international 10–20 system of electrode placement and are located over the bilateral arm/hand

somatosensory representation areas (Müller et al., 2017; Rigato et al., 2019). Additionally, we wanted to know whether mu band activity elicited by the three experimental conditions was specific to the centro-parietal region or extended to the occipital region (Cuevas et al., 2014). Thus, we also analyzed the channels over the occipital cortex (70, 74, 75, 82 and 83) corresponding to O1/Oz/O2 according to the international 10–20 system of electrode placement (Figure 2(b)). The average activity in the mu range was extracted for statistical analyses from these regions in all experimental conditions in the 100–500 ms time window. As for the selection of the frequency band, this time window was chosen based on visual inspection of activation elicited during the Touch condition, suggesting that activity reached its peak across participants within this time window. All
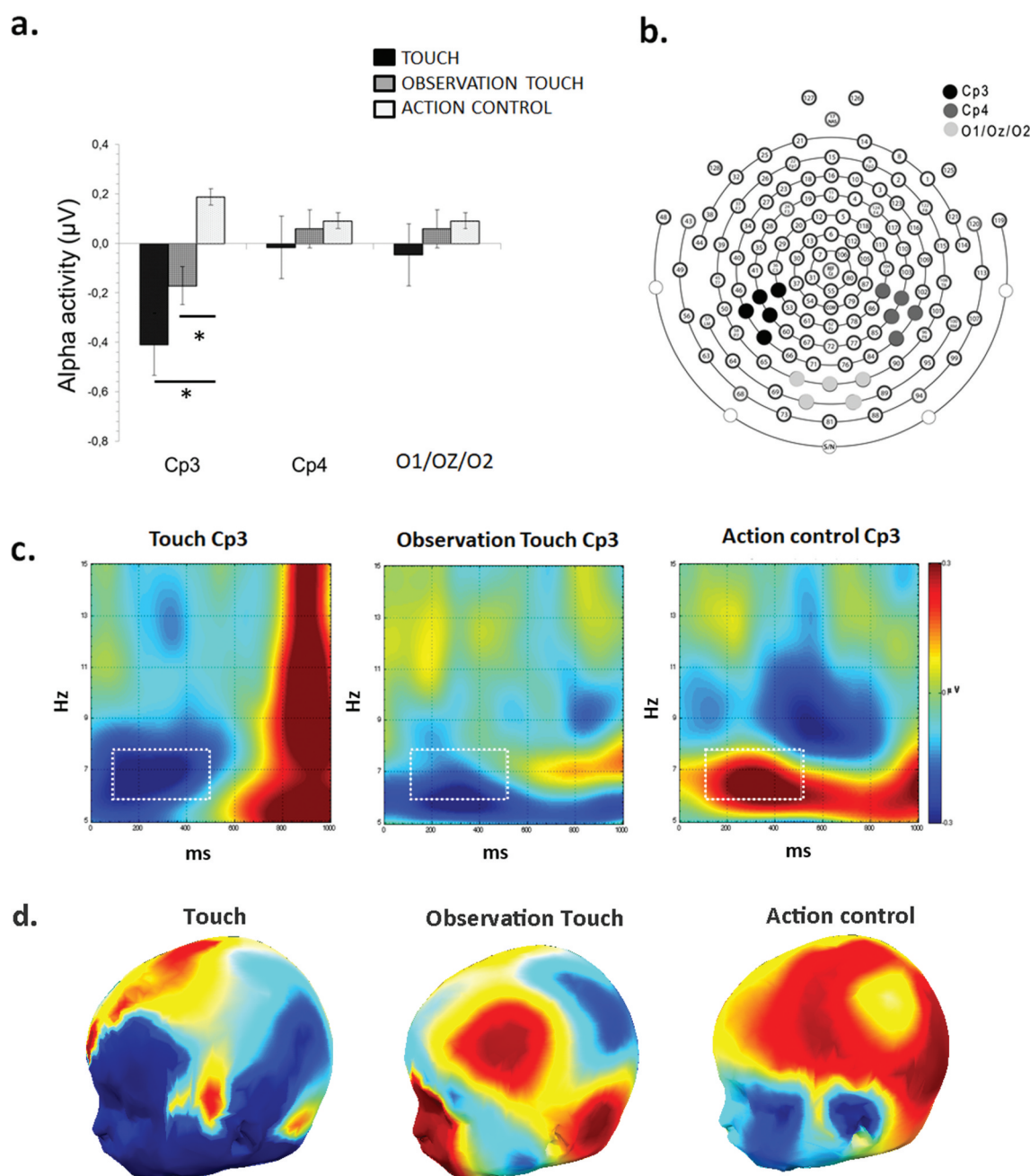

Figure 2. (a) Mean sensorimotor activation and significant comparisons between conditions in the Cp3, Cp4 and Occipital cluster; * p < .05. Error bars represent ± 1 standard error. (b) Schematic diagram of the 128-channels sensor layout showing the three Figure 2) clusters of electrodes (Cp3, Cp4 and O1/OZ/O2) (c) Time-frequency results during the three experimental conditions in correspondence of the Cp3 electrode cluster. (d) 3D graphical representation of mu band activity (6–8 Hz) in the 100–500 ms time window of the left hemisphere.

individual averages were also visually inspected to ensure the selected time window was appropriate.

EEG data were recorded, pre-processed using Netstation v4.6.4, and analyzed using WTools (see Parise & Csibra, 2013). All statistical tests were conducted on a .05 level of significance (two-tailed), pairwise comparisons were performed by applying t-tests and Fisher's least significant difference procedure (Howell, 2009), Holm-Bonferroni correction was used where appropriate (Abdi, 2010), as well as Greenhouse-Geisser correction for non-sphericity to adjust degrees of freedom.

Results

An initial 3×3 repeated measures analysis of variance (ANOVA) was conducted with Condition (Touch, Observation Touch, Action Control) as a between-subject factor and Electrode Cluster (Cp3, Cp4, Occipital) as a within-subject factor. The ANOVA revealed a significant main effect of Electrode Cluster, $F(1.13, 47.64) = 5.49$; $p = .02$, $\eta_p^2 = .12$, due to greater desynchronization over Cp3 ($M = -.13$ μV, $SD = .49$ μV) than Cp4 ($M = -.04$ μV, $SD = .45$ μV; $p < .01$) and the Occipital clusters ($M = -.04$ μV, $SD = .49$ μV; $p < .01$), irrespective of experimental condition. The main effect was qualified by a significant Cluster x Condition interaction, $F(2.27, 47.64) = 3.64$; $p = .03$, $\eta_p^2 = .15$. In order to inspect this interaction, paired sample comparisons were conducted separately within each electrode cluster. Post-hoc comparisons conducted over the Cp3 cluster demonstrated that there was significantly more desynchronization for the Touch ($M = -.41$ μV; $SD = .65$ μV), $t(28) = -3.32$; $p = .004$, $d = 1.2$, as well as for the Observation Touch condition ($M = -.17$ μV; $SD = .24$ μV), $t(28) = -3.51$; $p = .002$, $d = 1.3$, compared to the Action control condition ($M = .18$ μV, $SD = .31$ μV) (Figure 2(a)). All other differences over Cp3 were not significant (all $ps > .19$). Post-hoc comparisons conducted over Cp4 and the Occipital cluster did not obtain statistical significance (all $ps > .51$).

Additionally, one sample t-tests were performed to investigate the magnitude of mu desynchronization as compared to baseline over all electrode clusters in response to all experimental conditions. Mu band desynchronization was significantly different from zero over Cp3 in the Touch condition, $t(14) = -2.42$; $p = .03$, $d = .62$, and in the Observation Touch condition, $t(14) = -2.75$, $p = .02$, $d = .71$ (Figure 2(c)). Furthermore, significant mu band synchronization was observed over Cp3 in the Action Control condition, $t(14) = 2.31$, $p = .04$, $d = 59$. In the Cp4 and Occipital clusters, no activation obtained statistical significance (all $ps > .24$).

Discussion

The current study explored whether 8-month-old infants are able to share others' sensory experiences. EEG was measured while infants i) were stroked on their right hand (Touch condition); ii) observed a stroke on the right hand of another person (Observation Touch condition); ii) observed a stroke on somebody else's right hand with no tactile contact (Action control condition). Our results revealed mu rhythm desynchronization (6--8 Hz) of somatosensory sites contralateral to the hand being stroked (Cp3) in response to both felt and observed touch. No mu attenuation was found during the view of the hand movement, without any tactile stimulation (Action Control condition). Differential mu rhythm desynchronization was also found in the Touch and Observation Touch condition compared to the Action Control condition.

Our results support the existence of an early visuo-tactile mirror-like mechanism which may likely support in 8 month-old infants the interpersonal sharing of tactile sensations, in turn offering new interesting insights into the current literature (Drew et al., 2018; Meltzoff et al., 2018; Rigato et al., 2019; Müller et al., 2017). First, we demonstrated that mu desynchronization could be used as an index of infants' somatosensory resonance with others' tactile sensations by directly comparing felt and observed tactile experiences. Remarkably, our results show how fine-grained and selective is the involvement of somatosensory areas in response to others' tactile sensations in infancy. In fact, no mu rhythm attenuation emerged during the observation of a stroke that did not comprise a tactile component, but that possessed similar kinematic and visual features to the stroking gesture comprising a tactile stimulation.

It could be argued that such Action control condition represents a mimed touching action. In other words, one may claim that the difference we found in mu suppression in response to the observation of touching and no-touching gestures could rather reflect differences between, respectively, goal- and non-goal directed actions. Indeed, some studies demonstrated that mimed actions do not elicit mu desynchronization (even if in more central sites) compared to actions in which the outcome could be inferred (Southgate et al., 2010). However, other studies found mu rhythm suppression in the infant EEG in response to PLDs (Point-light-displays) configurations of mimed grasping actions (Quadrelli et al., 2019b) and in response to no-touching object-to-hand gestures (Müller et al., 2017). Differences in the visual stimuli used can account for these contrasting results. In the present study, infants were visually presented with long and continuous cutaneous

stimulation lasting for about 1000 ms. Thus, the stimuli used in the present study give emphasis to the tactile, rather than the action, component of the visual scene.

However, to better control for the differences between observation touch and action control conditions, it would be informative to add a further condition in which infants are shown with a hand caressing an object. Interestingly, some regions of the human tactile-mirror system seem to be best tuned to body-to-body tactile stimulations rather than to contacts involving objects (Blakemore et al., 2005; Pisoni et al., 2018; Rossetti et al., 2012). This further control condition could help to understand whether differences in mu suppression found in our study reflect a selective response to others' somatosensory experiences or, rather, to the goal-directedness, or even the familiarity of the observed actions.

An important novelty of our study is to have demonstrated mu-rhythm modulations during perception and observation of real-life tactile events. Regarding the first-hand experience of touch, previous studies explored infants' somatosensory responses to mechanical tactile stimulations, such as vibrotactile stimuli (Rigato et al., 2019) or punctuated touches produced by an inflatable diaphragm (Drew et al., 2018; Meltzoff et al., 2018). Remarkably, our study shows that somatosensory activity in infants could also be detected in response to naturalistic stimulations on the body, and is associated with a decreased activation in the infants' EEG mu rhythm. We have found such mu rhythm modulation also during the observation of real-life hand-to-hand tactile contacts. Differently, previous studies with infants have used video-stimuli to explore infants' somatosensory responses to observed touches (Meltzoff et al., 2018; Müller et al., 2017) while, in Drew et al. (2018), real-life touches were used within a visuo-tactile paradigm. It is plausible to think that naturalistic bodily touches might facilitate infants' ability to share others' tactile experiences, in turn affecting mu rhythm suppression in response to touch observation, as suggested by a study with 6-months-olds showing greater mu desynchronization in response to the view of live presentations compared to videos of reaching actions (Shimada & Hiraki, 2006).

Lastly, our study brings interesting advances in our knowledge about affective touch processing. Together with somatosensory feedback, interpersonal touch also conveys emotion and affective information, which contributes to infants' socio-emotional development (Feldman, 2011; Field, 2002). Affective touch was recently related to the discovery of human C-tactile (CT) afferent, which activates preferentially in response to affective strokes (i.e., affective slow stroking, < 10 cm/s) (McGlone et al., 2014),

and infants were shown to be sensitive to such affective stroking (Fairhurst et al., 2014; Jönsson et al., 2018; Miguel et al., 2019, 2020). In our study, infants received and observed slow affective strokes that most likely possess the kinematic features characterizing affective touch. Our results are in line with studies in adults demonstrating the involvement of α EEG bands during affective touch processing (Singh et al., 2014; Valenza et al., 2018; Von Mohr et al., 2018). Future studies should explore EEG modulations to touches that differ in valence by directly comparing EEG activity in response to felt and observed affective and non-affective tactile stimulations in infancy.

The use of a between-subject design represents a limitation of this study. Indeed, mu rhythm reactivity is sensitive to changes in attention state (Fox et al., 2016) and might also vary as a function of infants' level of alertness. However, it is unlikely that infants could stay engaged throughout three experimental live-sessions due to their limited attentional resources. It is important to note that, even if we don't have a specific measure of infants' attention (i.e., eye-tracking measures), no differences were found in mu desynchronization at occipital electrode sites across conditions, suggesting that the attention allocation was comparable. Also, the topographic specificity of mu rhythm responses found in our study suggests that such neural response might not be the result of more general attentional processes. Lastly, the Action control condition, by showing the same hand movement of the Touch Observation condition, allowed us to control for the differences in infant's attentional tracking of the observed tactile and no-tactile events.

In conclusion, our results shed new light on the current limited knowledge about vicarious processing of touch in infancy. The ability to share others' bodily experiences emerges very early in life and represents a building block for the understanding of others' bodily states and the development of human empathy.

Disclosure statement

No potential conflict of interest was reported by the authors.

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