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Socially-relevant Visual Stimulation Modulates Physiological Response to Affective Touch in Human Infants

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Abstract—The human tactile system is known to discriminate different types of touches, one of these termed 'affective touch', is mainly mediated by slow conducting tactile afferents (CT fibres), which are preferentially activated by slow and gentle strokes. Human infants experience self-generated tactile stimulation during prenatal life, and they receive a large amount of affectionate touches by their caregivers from birth. This early and extended experience with tactile stimulation may likely make infants particularly sensitive to affective touch, and increasing evidence shows that this may indeed be the case. However, infants commonly experience affective touch in the context of social interactions with familiar adults (e.g., while looking at their caregiver), and recent evidence suggests that this helps them assigning affiliative and communicative meaning to the touch they are perceiving. Here we investigated the presence of visual-tactile interactions in 4–5-month-old infants' physiological (i.e., skin conductance) and behavioural (i.e., visual looking times) responses to visual and tactile stimulation of affective/social nature when the sources of both stimulation are not familiar to the infant. To explore whether the modulation of physiological arousal elicited by the socially-relevant bimodal stimulation is specific to infants or extends into adulthood, we also tested a group of adults. Infants (*N* = 25) and adults (*N* = 25) were stimulated on their forearm through slow stroking (i.e. affective touch) or tapping (i.e. non-affective touch) during the observation of dynamic images of socially-relevant (i.e., an unfamiliar face) and non-socially-relevant (i.e., a house) stimuli. We found that the simultaneous presentation of socially-relevant visual-tactile stimuli significantly decreased infants' – but not the adults' – electrodermal response, suggesting that infants easily integrate low-level properties of affective touch with socially salient visual information, and that social experience may tune and change sensitivity to affective touch across the life-span.

Key words: affective touch, visual stimulation, multisensory, infants, CT-fibres, skin conductance response.

INTRODUCTION

The importance of social, affective touch has rapidly emerged in the past two decades, thanks to evidence that in most animal species (Dunbar, 2010), allogrooming (i.e., the grooming of others) plays a key role in social bonding. In humans and other primates (Harlow and Harlow, 1962; Simpson et al., 2019), physical expressions of affection mediated by touch delivered during infant-caregiver interactions are at the foundation of the development of secure attachment (Anisfeld et al., 1990), and an emotionally healthy brain (Feldman et al., 2013). Microneurographic studies have shown that, in the adult nervous system, affective touches delivered on the hairy skin induce preferential responses from a specific class of slow-conducting unmyelinated peripheral nerve fibres – i.e., C-Tactile fibres (CTs) – in the recipient. These fibres discharge more to medium-velocity (1–10 cm/s) and gentle brushing (0.3–2.5 mN), which commonly correspond to caress-like skin stroking than to other types of touches (Löken et al., 2009; McGlone et al., 2014; Gallace and Spence, 2016). Touches performed at intermediate velocity and thus eliciting CT fibres' activity, are also rated as more pleasant than touches performed at slower or faster velocity (for a review, see Liljencrantz and Olausson, 2014). Furthermore, intermediate-velocity strokes also activate regions that are typically involved in the affective processing of stimuli, such as the insula, the amygdala and the superior temporal sulcus (Olausson et al., 2002; Gordon et al., 2013). Thus, given these specific subjective, perceptual

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Abbreviations: CTs, C-Tactile fibres; SCR, Skin Conductance Response; vmPFC, ventromedial prefrontal cortex.

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and physiological correlates that are triggered by this type of touch, we will refer to it as 'affective touch', to underlie its hedonic nature and its recruitment of CT fibers, as done in other studies too (Gordon et al., 2013; McGlone et al., 2014).

The possibility that sensitivity to affective touch may represent a developmental default, or at least be present very early in life, has recently attracted the attention of many researchers, due to the potential clinical implications this could have (e.g., Gliga et al., 2018). Indeed, several studies have shown the beneficial effects of gentle tactile stimulation (i.e., massage) on weight gain (Field et al., 2006), stress regulation (Smith et al., 2013), and brain development (Guzzetta et al., 2011) in preterm infants. Recently, a study conducted on a large sample of preterm infants showed that a 5-min dynamic stroking (3 cm/sec) reduced infants' physiological arousal, as evidenced by heart rate and blood oxygen saturation levels, in comparison to a 5-min static touch (Manzotti et al., 2019). Interestingly, these physiological patterns were maintained even after the stimulation stopped (i.e., during a 5-min post-stimulation period), revealing the long-lasting benefits of affective touch. These studies provide robust evidence that sensitivity to affective touch early in life might be exploited to promote early rehabilitation techniques for infants at risk for neurodevelopmental disorders, such as preterm infants, as well as to trace atypical developmental trajectories (see e.g., Scheele et al., 2014).

Other studies have shown that from as early as 11 days of life (Tuulari et al., 2017), and throughout the first year of life (Fairhurst et al., 2014; Jönsson et al., 2018; Pirazzoli et al., 2019), affective and non-affective types of touch evoke different neural and behavioural responses in typically developing infant populations.

Recently, adult studies have revealed that other sensory stimulations, such as vision, may modulate the way touch is perceived and processed. For example, Gazzola and colleagues (2012) performed pleasant caresses on adult heterosexual male's legs while they viewed videos of visually attractive women or less attractive men. The authors found that activation in the somatosensory cortex was dependent upon perceived gender of the individual performing the caress, suggesting that top-down factors, such as socio-cognitive evaluations concerning the person's identity, and not the physical aspects of tactile stimulation per-se (i.e., low-level properties of touch), can modulate the perceived pleasantness of touch. This study is important because it suggests that rather than being hardwired in the human system, sensitivity to affective touch may be quite plastic and dependent upon contextual factors.

Interestingly, recent evidence suggests that top-down factors may already modulate the perceived pleasantness of gentle touch in the first year of life. For example, Aguirre and colleagues (2019) found that 9-month-old infants' heart rate decreased more when the infants perceived the affective touch (3 cm/s) as coming from their caregiver than when the same touch was delivered by an unfamiliar adult (note that the stimulation was always delivered by the same experimenter hidden to the infant). No difference in heart rate response between the touches delivered by the caregiver and the stranger emerged when the tactile stimulation was non-affective-like (0.3 cm/s and 30 cm/s). These findings suggest that, at least by 9 months of age, perception of affective touch in infancy is modulated by the familiarity of the social context.

Other studies have shown that, on the contrary, it is affective touch that modulates infants' response to visual stimulation. For example, Feldman and colleagues (2010) assessed stress response to a still-face through dosage of cortisol level in 4- to 6-month-old infants in the presence versus absence of concurrent maternal touch. The infants who were touched during the still-face paradigm exhibited a smaller increase in cortisol level in comparison to infants presented with the still-face alone, suggesting that interpersonal touch modulates infants' stress response during (atypical) dyadic interactions.

Overall, these studies provide evidence for bidirectional interactions between vision and touch in infants' responses to socially-relevant stimuli, in line with the evidence that multisensory information facilitates infants' selective attention and learning (e.g., Bahrick and Lickliter, 2012; Lloyd-Fox et al., 2015). However, it still remains to be established whether the social nature of the visual stimulation is capable of modulating the infant's response to the affective touch, when the sources of both the visual and the tactile stimulation are not familiar to the infant.

Answering this question has important clinical implications, as preterm infants are commonly treated by clinicians and other unfamiliar individuals, which makes it critical to understand whether the soothing effects generated by visuo-tactile stimulation provided by a familiar source like the caregiver generalize to unfamiliar sources as well.

In light of this evidence, in the current study we addressed the existence of bidirectional influences of vision-to-affective touch and affective touch-to-vision in a group of 4–5-month-old infants, who were presented with dynamic images of a socially-relevant stimulus (i.e., an unfamiliar female face) and a non-socially relevant stimulus (i.e., a house), while concurrently receiving affective-like (i.e., slow and continuous) vs non-affective-like (i.e., tapping) strokes on their forearm.

In particular, from a theoretical standpoint, our study aimed to answer the general question of whether tactile processing is modulated by the social nature of concurrent information conveyed by other sensory modalities (vision in this case). Studies have shown that infants can extract amodal invariant relations across senses (Bahrick and Lickliter, 2012) and show cross-modal transfer between vision and touch by at least 5 months of age (Streri and Pêcheux, 1986; Coubart et al., 2015). We thus hypothesised that infants would process the redundant social and affective meaning conveyed by vision and touch by displaying lower physiological arousal when they were presented with the face stimulus while being stroked continuously. Importantly, for the first time in infant research, we measured

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physiological arousal in response to affective touch by recording Skin Conductance Response (SCR), a measure that signals changes in the activation of the autonomic nervous system (Critchley et al., 2000). SCR is particularly suited to be used in studies investigating individuals' responses to affective and emotional stimuli, including expressions of affection conveyed by touch, as recently investigated in adults (Chatel-Goldman et al., 2014; Pawling et al., 2017; Etzi et al., 2018). Few studies so far have used SCR to explore the psychophysiological foundations of infant emotion and emotional development under visual stimulation conditions (e.g., Ham and Tronick, 2006, 2008; Nava et al., 2016; Nava and Turati, 2020); the current study extends these earlier studies by measuring SCR to explore infants' perception of the affective properties of sensory stimulation provided by other senses.

To further explore how physiological reactions to affective touch are modulated by experience, and how the interaction between affective touch and vision changes between infancy and adulthood, we also included a group of young adults. They were tested under the same exact conditions as the infants, with the only exception that they were explicitly instructed to attend to each of the images presented on the screen throughout the experiment.

A secondary reason for testing adults is that the literature on autonomic responses to affective and non-affective touch does not always converge; for example, Pawling and colleagues (2017) reported that an affective-like, slow touch (3 cm/sec) was rated as more pleasant and produced larger heart rate deceleration and larger decrease in SCR than a faster type of touch (30 cm/sec). Etzi and colleagues (2018) extended the results of Pawling and colleagues (2017), revealing that, although low stroking was evaluated as being more pleasant and relaxing than other tactile stimulations, when the non-affective touch is represented by a simple discriminative touch, such as tapping, this produces lower arousal in comparison to both 3 cm/s (slow, affective touch) and 30 cm/s (fast, non-affective touch), suggesting that subjective pleasantness may not always correspond to lower autonomic activity.

Thus, based on the available evidence, different physiological responses resulting from affective and non-affective touch in adults depend on the specific type of touch used as non-affective. Here, because we used tapping as non-affective touch stimulus, we expected to observe higher SC responses in the affective condition in adults with respect to the non-affective condition. In contrast, for infants we expected to observe a larger deflection in the amplitude of electrodermal activity in response to the concurrent presentation of visual and tactile stimulation of affective/social nature (i.e., when they were presented with the face stimulus while being stroked continuously) than to all the other stimulation conditions (i.e., when the house stimulus was associated to the continuous stroke or the face stimulus was associated to the tapping tactile stimulation). Moreover, in light of the evidence that social touch affects infants' visual responses to social stimuli (e.g. Della Longa et al., 2019), we expected to observe longer looking times to the face when infants concurrently received an affective-like touch compared to when they received a tapping stimulation.

EXPERIMENTAL PROCEDURES

Participants

Thirty-eight 4–5-month-old, full-term, infants (19 females, mean age = 141 days, age range: 123–179 days), and 25 adults (17 females, mean age = 24, age range: 19–31 years) participated in the study. All participants were cognitively and neurologically healthy, and did not present visual or tactile deficits. The data of 13 infants were discarded from final analyses, due to fussiness resulting in failure to complete at least two trials for each condition ($N = 8$), technical difficulties ($N = 2$) or poor skin conductance data ($N = 3$). This resulted in a final sample of 25 infants. The final samples size for both the adult and the infant groups were in accord with the a priori calculation of estimated sample size, performed with GPower (effect size = 0.25, $\alpha = 0.05$, Power = 0.80, 1 group, 4 measurements), which required 24 participants. Infants were recruited via a written invitation that was sent to parents based on birth records provided by neighbouring cities. At least one parent provided written informed consent before testing began. Adults were students of the University of Milano-Bicocca and received course credits for their participation in the study. All signed a written informed consent before testing. The protocol was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and approved by the Ethics Committee of the University of Milano-Bicocca.

Stimuli

Participants were presented with concurrent visual and tactile stimuli. The visual stimuli consisted of two 10-second-videos, one depicting a silent young female talking face (i.e., social stimulus), the other a house with a moving door (i.e., non-social object) (see Fig. 1), both

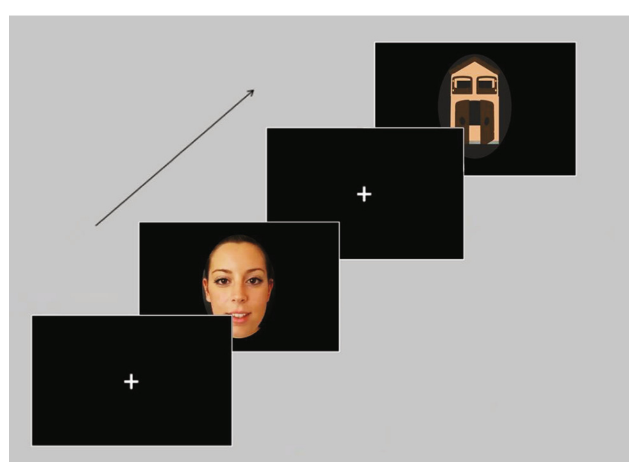

Fig. 1. Schematic description of the stimuli and procedure.

presented on a black background. The face pronounced a sentence ("Hello, how are you? Today is raining, tomorrow the sun will shine.") that covered the whole 10 s presentation, with no sound associated to the movement of the mouth and the eyes blinking five times. The house was designed to resemble the human face as much as possible. In particular, colours matched those of the face, in that two windows mimicked the eyes and a brown door mimicked the mouth. The door opened and closed 5 times within the 10-second-presentation. Both the face and the house appeared within an oval black frame so that they were equal in size (11 × 14 cm).

The tactile stimuli for both infants and adults consisted of two types of touches performed with a small paintbrush: a slow and gentle stroke (i.e. affective touch) performed on the right forearm over a 6-cm-marked area at a 3 cm/s velocity. The stroking was performed in a proximo-distal direction (i.e., from elbow to wrist) and repeated three times, which ended up in an overall stimulation duration of 6 s The second type of stimulus was a non-affective type of touch (i.e. tapping) consisting of 3 taps performed along the same 6-cm-marked area from elbow to wrist and repeated twice over 6 s (i.e., 1 tap/second), which ended up in 6 taps. The two types of touches were delivered by a trained experimenter, who received auditory tracks through headphones of the onset and offset of the stroking, as well as the correct velocity to be applied during the two types of touch (following Gazzola et al., 2012). For the affective touch, the auditory signal consisted of three two-second-long glissando tones while for the non-affective touch it consisted of six one-second-long beeps. Although we were not able to control the pressure of the stroking, the same trained experimenter stroked all the infants, and the same applied to the adults.

Procedure

Adults and infants were tested using the same procedure, with a few exceptions. Adult participants seated at 60 cm from the monitor (a 24-inch monitor, 1920 × 1200-pixel resolution, refresh rate of 60 Hz); the infants seated on her/his parent's lap, with the face directed toward the monitor at a distance of about 50–60 cm. Infants' fixations were recorded through a video camera positioned just above the monitor and directed to the participant's face. For adults, the electrodes were attached to the left hand, while for infants they were attached to the left foot. Once the electrodes were positioned, one experimenter, placed behind a black curtain, started the presentation of a white fixation cross, and, as soon as the participant fixated the cross, turned on the first video. Participants were presented with a maximum of 10 trial blocks, each consisting of four videos alternating the face and the house, for a total of 40 trials. Each block was accompanied by a different type of touch (affective or non-affective), so that there were four consecutive trials delivering either the affective or non-affective touch. Infants went through an average of 21 trials (range = 10–37), while all adults watched the entire 40 trials. Half of the participants within each age groups started with the face video, while the other half started with the house video. The type of touch was also counterbalanced across participants, so that half started with the affective-touch trial block and the other half with the non-affective-touch trial block. The type of touch was also counterbalanced across participants, so that half started with the affective-touch trial block and the other half with the non-affective-touch trial block. The interstimulus interval varied for infants and adults, as it was fixed at 500 ms for the adults and varied depending on the duration of each participant's attention for the infants. Once a trial ended, a fixation cross appeared on the screen; as soon as the infant fixated the monitor, the experimenter started the new video by button press. If needed, the experimenter re-attracted the infant's attention by presenting an attention getter (i.e., a short animation), which was turned off when the infant look back at the screen, and the following trial could start. Infants went through an average of 21 trials (range = 10–37), while all adults watched the entire 40 trials.

For both infants and adults, a second female experimenter performed the tactile stimulation on the participant's right forearm. The onset of the visual stimuli corresponded to the onset of the auditory tracks, signalling the experimenter to start stroking. The experimenter was seated next to the participant on her/his right side and held her/his arm throughout the experiment to allow the stroking to be more controlled, and to avoid large movements.

There were no breaks throughout the experiment, and the infants were presented with the videos and the strokes until s/he got distracted or too tired to continue watching. The entire experimental session took approximately 20 min for the adult participants and 10–15 min for the infants. Duration of infants' looking times were offline coded by two experimenters naïve to the experimental condition using VirtualDub (http://www.virtualdub.org/), a video capture/processing utility that allows watching videos in a frame-by-frame fashion. Intercoder agreement (Pearson correlation) between the two observers, as computed on total fixation times on the presented face and house videos, was $r = 0.98$.

SCR data collection and analysis

SCR was recorded using an MP160 biosignal amplifier working with the specific acquisition module for electrodermal activity GSR100-C (Biopac Systems, Inc.). The amplifier was connected to the computer through an optical connection. The gain parameter was set at 5 mmho/V and the signal sampled at 100 Hz. The signal was acquired by applying two pre-gelled, self-adhesive, AgAgeCl electrodes with circular contact areas 1 cm in diameter, directly on the plantar surface of the infant foot (heel and outer edge, see Ham and Tronick, 2008), and on the 2nd and 4th digit in the adults. Electrodes were secured using adhesive collars. The analyses of SCR were conducted using AcqKnowledge Software provided by Biopac Systems, which transforms skin conductance level data to provide a SCR by means of a high pass digital filter set at 0.05 Hz. For each

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participant, we extracted the peak-to-peak from each trial, as calculated by subtracting the maximum from the minimum peak within each single trial, in line with previous studies (see Nava et al., 2016; Nava and Turati, 2020). All movement artefacts were removed from the final analysis. SCR data were analysed separately for adults and infants because the physiology of the skin changes across the first year of life, and the sympathetic nervous system associated with arousal undergoes important developmental changes during the first 10 weeks of life (Hernes et al., 2002).

RESULTS

Data analysis

For both adults and infants, mean peak-to-peak of each participant was entered as the dependent variable into two repeated-measures ANOVAs, one for each age group, with Type of Touch (affective vs. non-affective) and Type of Visual Stimulation (social vs. non-social) as within-subjects factors. For infants, we also performed a second 2×2 repeated-measures ANOVA on mean looking times, with Type of Touch and Type of Visual Stimulation as within-subjects factors.

Adults

The SCR data only revealed a main effect of Type of Touch, $F(1,24) = 10.17$, $p = 0.004$, $\eta p^2 = 0.30$, which was due to the signal being higher in amplitude in response to the affective touch ($M = 0.09$, $SD = 0.08$) in comparison to the non-affective touch ($M = 0.06$, $SD = 0.06$, $p < 0.002$, Bonferroni corrected) (see Fig. 2).

Infants

The ANOVA conducted on SCR revealed a significant Type of Touch $\times$ Type of Visual Stimulation interaction, $F(1,24) = 4.56$, $p = 0.04$, $\eta p^2 = 0.16$, and no significant main effects (both $p > 0.10$). Post-hoc Bonferroni corrected tests showed that signal amplitudes were lower in the condition in which the affective touch was coupled with the face ($M = 0.85$, $SD = 0.64$) in comparison to all the other conditions ($p < 0.04$) (see Fig. 3). No other comparison was significant, and in particular there was no difference between the affective and non-social affective conditions when coupled with the house ($p > 0.99$), and the two non-affective touch conditions did not differ from each other ($p > 0.99$).

The ANOVA conducted on mean looking times revealed a main effect of Type of Visual Stimulation, $F(1,24) = 15.84$, $p < 0.001$, $\eta p^2 = 0.40$, and no significant Type of Touch $\times$ Type of Visual Stimulation interaction ($p = 0.69$). Bonferroni post-hoc tests showed that looking times directed to the face ($M = 8408$ ms, $SD = 1134$) were longer than those directed to the house ($M = 7490$ ms, SD 1046, $p < 0.001$), irrespective of the type of tactile stimulation delivered to the infant ($p = 0.69$) (see Fig. 4).

DISCUSSION

In the current study, we investigated whether infants' and adults' physiological response is modulated by the social nature of visual and tactile stimuli, in the absence of familiar sources of stimulation. Results showed that this was indeed the case, but only as assessed through electrodermal activity. When the stimulus had a (bimodal) social nature, infants displayed a significant decrease in SCR, suggesting that a socially-relevant visual stimulus in association with an affective touch, even if unfamiliar to the infant, can produce soothing responses in 4-month-old infants. On the contrary, the (bimodal) social nature of the stimulus did not influence infants' behavioural response, as their visual attention was always robustly directed towards the face, irrespective of type of touch received.

Adults, unlike infants, displayed higher SCR to affective-like touch (i.e. slow stroking) than to non-affective touch (i.e. tapping), as shown in previous studies (Etzi et al., 2018), and this pattern was not affected by the nature of the visual stimulation. This pattern of results might seem in contrast with earlier

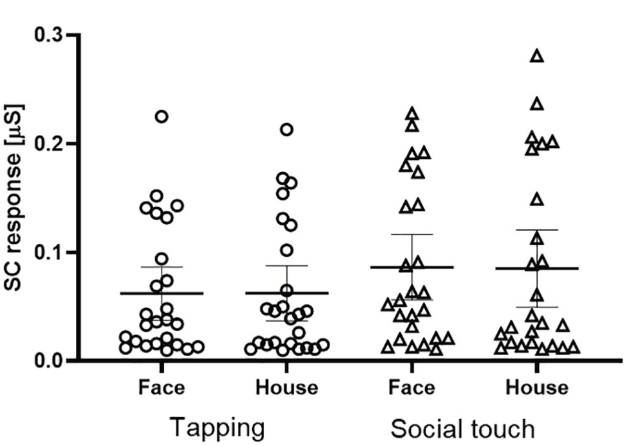

Fig. 2. Skin Conductance Responses (SCRs) elicited in adult participants by either tapping or affective touch during the observation of the social (i.e., face) and non-social (i.e., house) visual stimulus. Error bars indicate 95% confidence interval of the mean.

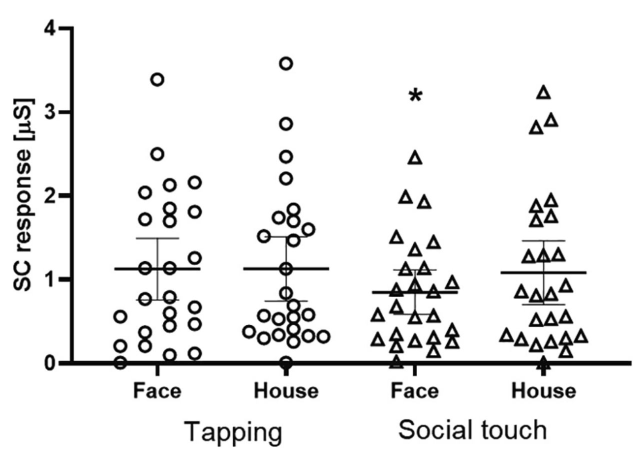

Fig. 3. Skin Conductance Responses (SCRs) elicited in infant participants by either tapping or affective touch during the observation of the social (i.e., face) and non-social (i.e., house) visual stimulus. Error bars indicate 95% confidence interval of the mean.

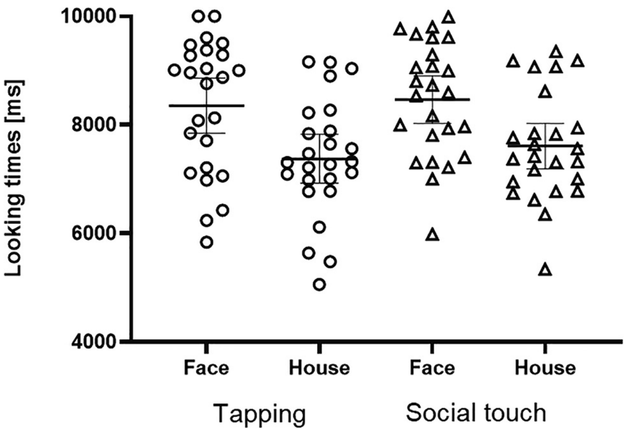

Fig. 4. Looking times (in milliseconds) of infants to the visual stimulus following either tapping or affective touch. Error bars indicate 95% confidence interval of the mean.

demonstration that adults' neural response to a pleasant touch is modulated by the visual stimuli simultaneously presented (Gazzola et al., 2012), but important methodological differences may explain the discrepancy in the results. Indeed, the social visual stimulus used in Gazzola et al. (2012; i.e., the video of an attractive woman delivering the touch) was likely much more salient for the adult participants than the dynamic isolated face image presented in the current study, and this lack of saliency may have masked any potential influence of social visual stimulation on the adults' SCR.

We argue that the difference in the direction of SCR modulation produced by affective touch in infants and adults may reflect differences in the emotional and affective valence of the social context in which affective touch is experienced. While infants experience affective touch in the reassuring and familiar context provided by caregiving and dyadic interactions, adults typically experience this type of touch in the context of close interpersonal relationships entailing physical intimacy and sensual/sexual implications. This difference may reflect in the observed decrease in arousal in response to affective touch in infants, and the corresponding increase in adults' arousal, overall suggesting that sensitivity to affective touch would be tuned by social experience and thus change across the lifespan.

It remains to be explained how affective touch gets integrated with face perception in the infant's brain, and how this integration results into modulations of electrodermal activity. First, Johnson (2005) has proposed that a ''quick and dirty" subcortical pathway for face detection is present at birth and triggers the development of the more sophisticated and cortically-represented network that supports face recognition in adulthood. That is, earlier in development, faces would be ''seen" at a subcortical level. Interestingly, there is also evidence not only that the CT-mediated touch system involves both cortical and subcortical brain regions (Morrison, 2016), but, most importantly, that a network of cortical and subcortical systems, all connected to the ventromedial prefrontal cortex (vmPFC), integrates affective and socially-relevant sensory cues. In particular, the vmPFC would act as a hub that links a variety of neural systems involved in the representation of the affective qualities of sensory events, and their social and emotional valence (Roy et al., 2012). Within this framework, we could speculate that, earlier in development, affective touch and faces might be likely integrated and processed at a subcortical level. Studies have also revealed that, in adults, stimulus-driven changes in SCR parallel changes in the activation of subcortical neural structures, such as the amygdala, particularly when the stimuli presented convey emotional meaning (Morris et al., 1999). Thus, our finding that affective touch delivered during visual inspection of a face decreased SCR may reflect changes occurring in shared subcortical brain regions. In line with earlier demonstration that affective touch can facilitate infants' discrimination of face identity (Della Longa et al., 2019), our findings may suggest that, by dampening physiological arousal, affective touch would contribute to facilitate the processing of socially-relevant information available through other sensory modalities, including vision.

Furthermore, our physiological findings have important methodological and clinical implications. From a methodological perspective, the physiological changes observed in electrodermal activity extends the notion that skin conductance provides a non-invasive and reliable tool for measuring physiological arousal in typically developing infants (see Nava et al., 2016; Nava & Turati, 2020), as well as in clinical infant populations (Harrison et al., 2006). Moreover, our study is the first to use such method to investigate sensitivity to multimodal stimulation of social nature, and the fact that we observed modulations in arousal across our experimental conditions suggests that skin conductance provides a sensitive measure of infants' affective states. Indeed, the decrease in the amplitude of electrodermal activity when the infants received socially-relevant visual-tactile stimulation parallels the findings of Aguirre et al. (2019) and Fairhurst et al. (2014), who both reported heart rate deceleration when infants received affective-like tactile stimulation. Because heart-rate and skin conductance both reflect activity in the autonomic nervous system, our and Aguirre et al. (2019) and Fairhurst et al. (2014) results, together, reveal that this system is already tuned to social-like stimulation across different sensory modalities by the age of 4 months.

From a clinical perspective, our study corroborates findings that suggest that touch therapy, including massage, kangaroo care and osteopathic manipulative treatment, all may have beneficial effects on the infants' well-being and developmental outcomes, being associated with decreased stress response and autonomic arousal, improved pain tolerance, enhanced immune-system parameters, and improvements in attentional responses and cognitive and motor development (Feldman et al., 2002; Hernandez-Reif et al., 2007; Manzotti et al., 2019). Most of these studies analysed the effects of tactile stimulation occurring in the context of dyadic interaction with the caregiver, whereas in clinical settings infants are most commonly handled by clinicians or researchers. Our results show that affective touch modulates infants' physiological arousal even

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when performed by an unfamiliar individual and suggest that performing the tactile stimulation while the infant faces the researcher/clinician may enhance the beneficial effects of the touch itself.

One caveat of the current results is that infants' selective sensitivity to redundant visual-tactile social cues was only visible in their physiological response, and not in their behavioural response, as infants' looking times were not modulated by the affective versus non-affective nature of the tactile stimulation. This dissociation between physiological and behavioural responses may depend upon the saliency of the social visual stimulus, i.e., the face. It is well-known that, from birth onwards, attention is preferentially recruited by faces over non-face stimuli (e.g., Palermo and Rhodes, 2007), and, in line with these findings, infants in the current study displayed longer looking times to the face than to the house, irrespective of type of touch (see Fig. 4). Our hypothesis is that the heightened and sustained attentional response to the face might have masked any modulatory effect of touch on looking time duration, with touch being nonetheless processed at a more implicit level, i.e., the autonomic nervous system. It should be noted that similar dissociations between SC responses and looking time measures have been observed in other infant studies too (Nava et al., 2016; Nava and Turati, 2020), suggesting that sensory and social information can be processed covertly at a physiological level without influencing overt behaviour (i.e., looking times).

The idea that the saliency of the face might have masked any influence of affective touch might also explain the apparent conflict with the results of Della Longa et al. (2019), who showed that social touch affects 4-month-old infants' ability to learn and discriminate a familiarized face from a novel one, as assessed with looking times. Indeed, Della Longa et al. (2019) tested face discrimination abilities by presenting infants with two facial identities, a previously familiarized identity and a novel one, and by measuring novelty preference responses. In contrast, we simply measured face detection abilities by presenting infants with one single face and a non-face stimulus alternating on the screen. Therefore, unlike Della Longa et al. (2019), our looking time data do not inform us on the type of processing infants performed while attending to the stimuli, and so they are blind to any possible facilitating effect of touch on the processing of identity diagnostic information from the attended face. Again, the attention-grabbing power of the face in itself might have masked the influence of affective touch in our study, while favouring the in-depth processing of facial information that leads to identity discrimination in the study of Della Longa et al. (2019).

In conclusion, our findings show for the first time that physiological sensitivity to affective touch in infants is modulated by the presence of social visual stimuli, even when no familiar source of stimulation is involved. They suggest that sensitivity to visual-tactile stimulation in the earlier stages of development is broadly tuned to social information and would narrow across development as a result of social experience with the caregiver and familiar adults.

AUTHOR CONTRIBUTIONS

All authors contributed to the development of the study concept. All authors contributed to the study design. Testing and data collection were performed by EN and RE. EN performed the data analysis. EN and VMC drafted the manuscript. All authors approved the final version of the manuscript for submission.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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