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Processing social and emotional actions and gestures in infancy

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Table of Contents

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Abstract

Starting from birth, we daily observe and experience social interactions - i.e., eye contact, being held or being smiled at. Frequently, infants are not directly involved in social interactions, but they observe the social interactions that populate their surrounding environment. Using neurophysiological (Event Related Potentials, ERP; electromyography, EMG) and behavioral measures (preferential looking procedure), we aimed to further investigate infants' responses to observed social signals, examining: i) the infants' neural electrical activity elicited by the observation of prosocial and antisocial actions (Chapter 1), ii) infants' ability to extract emotional information from an observed touching gesture (Chapter 2), and iii) the modulation exerted by their mother touch on infants' attention to emotional stimuli (Chapter 3).

Our research results found that neural activity of 5-to-6 months old infants differentiate observed prosocial and antisocial actions: the elicitation of specific ERP components showed that more allocation of attention was given to the antisocial action, while more cognitive resources were devoted to the processing of the prosocial action (Chapter 1). Additionally, 11-month-olds' facial muscles activity was congruent to the observed positive tactile interactions (caress of an arm), as shown by increased activity of the zygomaticus major muscle (ZM, activated in smiling). Conversely, no differential facial responses to observed negative tactile interactions (scratch of an arm) emerged (Chapter 2). Lastly, we demonstrated that experiences of maternal touch modulate infants' attention to emotional stimuli. Infants who received affective touch and had a greater frequency score of past touch experience had a diminished avoidance of the angry faces; conversely, those in the non-affective touch condition and a higher touch frequency score tended to avoid angry faces more (Chapter 3). Overall, these findings add insights to the topic of early social cognition, shedding new light on how infants process social interactions.

Abstract (Italian Version)

A partire dalla nascita, osserviamo e sperimentiamo quotidianamente le interazioni sociali, ad esempio il contatto visivo, l'essere abbracciati o il sorriso altrui. A volte, i bambini non sono direttamente coinvolti nelle interazioni sociali, ma osservano le interazioni sociali che popolano l'ambiente che li circonda. Utilizzando misure neurofisiologiche (potenziali evento correlati, ERP; elettromiografia, EMG) e comportamentali (preferenza visiva), ci siamo proposti di indagare le risposte dei bambini nel primo anno di vita ai segnali sociali osservati, esaminando: i) i correlati neurali elicitati dall'osservazione di azioni prosociali e azioni antisociali (Capitolo 1), ii) la capacità dei bambini di cogliere le informazioni emotive veicolate da un gesto che implica un contatto tattile (Capitolo 2) e iii) la modulazione esercitata dal tocco della madre sull'attenzione del bambino agli stimoli emotivi (Capitolo 3).

I risultati delle nostre ricerche dimostrano che l'attività neurale dei bambini di 5-6 mesi differenzia le azioni prosociali rispetto a quelle antisociali: l'elicitazione di specifiche componenti ERP ha mostrato che i bambini prestano maggiore attenzione alle interazioni antisociali, dedicando invece maggiori risorse cognitive all'elaborazione delle interazioni prosociali (Capitolo 1). Inoltre, i nostri risultati indicano che, a 11 mesi di vita, l'attività dei muscoli facciali è congruente alle interazioni tattili positive osservate (carezze), poiché è stata riscontrata una attività più accentuata del muscolo zigomatico (ZM, che si attiva quando sorridiamo), ma nessuna attività differenziata dei muscoli facciali in risposta alle interazioni tattili negative osservate (graffio) (Capitolo 2). Infine, abbiamo dimostrato che l'esperienza del tocco materno è in grado di modulare l'attenzione dei bambini agli stimoli emotivi. I bambini che hanno ricevuto un tocco affettivo e hanno avuto una maggiore frequenza di esperienze tattili passate hanno mostrato in minor misura un pattern di evitamento verso i volti arrabbiati; al contrario, coloro che hanno avuto la stessa esperienza passata con il tatto ma hanno ricevuto un tocco non affettivo tendevano ad evitare i volti arrabbiati (Capitolo 3). Nel complesso, questi risultati approfondiscono le nostre conoscenze circa la cognizione sociale precoce, gettando nuova luce circa le modalità attraverso le quali i bambini in età infantile elaborano le interazioni sociali che osservano.

General Introduction

Observing and Interacting with the social world early in life

Social interactions are not only represented by conversations between people or overly complex social encounters, as they can be as simple as making eye contact or touching another person. Social cognition focuses on how people process, store, and apply information about other people, for example, understanding another person's emotions, actions, and intentions and how they use that information in a social setting (De Jaegher, Di Paolo, & Gallagher, 2010). Infants, while limited in their responses, are constantly having social interactions from being held to being smiled at. Soon after birth, newborns manifest certain social preferences, such as an inclination to look at face stimuli (Johnson, 2005), a preference for faces who make direct eye contact over averted gaze (Farroni, Csibra, Simion & Johnson, 2002), and for happy faces over neutral ones (Rigato, Menon, Johnson & Farroni, 2011). Furthermore, a study in utero showed twins performing movements directed to one another (Castiello et al., 2010). Overall, these findings suggest a strong inclination toward social input very early in life.

Not only are we directly involved in social interactions, but we often observe them happening to other people around us. By observing interactions between others, one can tell a great deal of information about the individuals involved, such as their emotional state, desire, or belief. At a very young age, infants are sensitive to social interactions and show a behavioral preference, through looking times and manual choice tasks, to agents that behave in a way that is seen as helpful or kind (prosocial) over others who act in an unhelpful or mean (antisocial) way (Hamlin & Wynn, 2011; Hamlin, Wynn, & Bloom, 2007; Hamlin, 2015). These early social inclinations can be considered as the building blocks of sociomoral evaluations.

Social interactions frequently involve physical contact, whether it is a handshake, a hug, or even a poke on the arm, they commonly involve a touch of some kind. Recent neuroscience evidence has shown a connection between the observation of touch and activation of the observer's somatosensory areas (Ebisch, Perrucci, Ferretti, Del Gratta, Romani, & Gallese, 2008; Meltzoff, Ramirex, Saby, Larson, Taulu, & Marshall, 2018; Bolognini, Rossetti, Fusaro, Vallar, & Miniussi, 2014; Rossetti, Miniussi, Maravita, & Bolognini, 2012). For instance, a magnetoencephalography (MEG) study found that the primary somatosensory (SI) cortex, which is mainly active when we are being touched (Ploner, Schmitz, Freund, & Schnitzler, 1999), is also activated when we just watch others being touched (Pihko, Nangini, Jousmaki, & Hari, 2010; Keysers, Kaas, & Gazzola, 2010). Furthermore, infants before their first year of life activate their own primary somatosensory cortex during the observation of touch, with a pattern of activity comparable to that recorded when they receive a touch to their own body, thus showing that they have a neural representation of both their own and other bodies (Meltzoff et al., 2018).

Touch is an important part of interacting socially, as social touch is a critical aspect and a main component for a plethora of social interactions. The types of touch either observed or received can project different emotional states: adults are very good at decoding emotions from different kinds of touch both when they experience touch and when they observe other touching experiences (Hertenstein, Keltner, App, Bulleit, & Jaskolka, 2006; Bolognini, Rossetti, Convento, & Vallar, 2013). An Event Related Potential (ERP) study found that 6-month-old infants showed higher amplitude of the NC component (which is an index of attention) when observing painful stimuli (being poked in the eye) vs. neutral stimuli (being touched on the forehead) (Addabbo, Bolognini, & Turati, 2021), demonstrating that infants are sensitive to others unpleasant emotional experiences. Infants are also sensitive to emotions given off by body language when individuals interact with an object, demonstrating that they also have the ability to extract emotional affective content from the kinematic movement of others (Addabbo, Vacaru, Meyer, & Hunnius, 2020).

Touch, in general, is an critical part of infant development and communication. Even in the animal kingdom, parental touch exposure gives their offspring's system a relaxing or destressing effect (Liu et al., 1997; Weaver et al., 2004). In preterm infants, skin-to-skin contact, like in kangaroo care where the infant's body has direct contact with the caregivers, promotes rapid improvements in their development of autonomic and sleep systems (Feldman & Eidelman, 2007; Feldman, Rosenthal, & Eidelman, 2014). As infants are sensitive to touch, some studies have investigated whether touch can modulate infants' attention or behavior toward social stimuli. Indeed, a recent study showed that touch can exert an effect on infants' attentional resources, with infants being able to discriminate facial identities better when provided with a gentle stroke than those who experienced a non-social touch (Della Longa, Gliga, & Farroni, 2019). Even in late childhood, a brief maternal touch on the child's shoulder was found to lower the child's attention to socially threatening stimuli (angry facial expressions) (Brummelman, Terburg, Smit, Bogels, & Bos, 2019).

The aim of this thesis is to investigate infants' responses to observed social signals, focusing on: i) the neural electrical activity elicited by the observation of the prosocial and antisocial events, ii) infants' ability to extract emotional information from a touch interaction, and iii) modulation exerted by touch on infant's attention to emotional stimuli.

More specifically, the first chapter will be dedicated to a deeper understanding of 5-to-6 months old infants' ability to differentiate between two observed dynamic social interactions (prosocial and antisocial), investigating their neural underpinnings. It is known that infants as young as 3 months of age manifest a visual preference toward prosocial individuals, looking longer at those who behave in a prosocial way over those who behave in an antisocial way (Hamlin, Wynn & Bloom, 2010). Once at 6 months, infants repeatedly reach with their hand towards the prosocial characters while avoiding the antisocial one (Hamlin & Wynn, 2011; Van de Vondervoort & Hamlin, 2018). Nonetheless, only one study has examined the neural correlates of infants' processing of prosocial and antisocial characters during the first year of life (at 6 months of age, Gredebäck et al., 2015). In Chapter 1, a study will be presented that aims to fill this gap, recording infants' ERP components elicited through the observation of dynamic prosocial and antisocial events.

The aim of the study presented in Chapter 2 was to investigate whether infants' sensorimotor system was involved in the processing of observed emotional interpersonal interactions. To this aim, 11-month-old infants' facial electromyographic (EMG) responses to the observation of emotional, interpersonal touch were recorded. In fact, in adults, several studies have shown evidence of a visual-mirror tactile system, demonstrating that the observer's somatosensory system engages during the observation of a touch to another person (Keysers et al., 2010; Meltzoff et al., 2018; Rigato, Banissy, Romanska, Thomas, van Velzen, & Bremner, 2019; Addabbo et al., 2021). Within the developmental population, a congruency between the activation of infants' facial muscles and the observed happy and fearful facial expressions has been shown (Kaiser, Magdalena Cresp- Llado, Turati, & Geangu, 2017; Datyner, Henry, & Richmond, 2017). Furthermore, infants' facial muscles also respond congruently to the emotions expressed by kinematic information embedded in a grasping movement (moving an object with a happy motion or angry motion) (Addabbo et al., 2020): observing the angry kinematic movements elicited larger activity of the corrugator supercilia (CS) muscle, which is typically activated when observing angry stimuli, while observing the happy kinematic movement induced increased activation of the zygomaticus major (ZM) muscle, usually activated when we smile.

Lastly, the study presented in Chapter 3 investigates whether and how maternal touch modulates 7-month-old infants' attention to observed emotional stimuli. Specifically, we examine how experience with their mothers' touch modulates infants' attention: mothers will either give a gentle stroke (affective touch) or a slow squeeze (non-affective touch) on the arm of their infant while they watch the emotional stimuli. A study by Tanaka, Kanakogi, and Myowa (2021) found that infants with more physical contact had less evasive behaviors with a stranger and facilitated exploration of non-familiar objects compared to infants who had less physical contact, demonstrating that maternal touch gives infants a kind of security that modulates infant's behaviors to people or objects. The aim of this last chapter is to examine whether and how these two different maternal touches (affective vs non-affective) effect infants' sensitivities to emotional facial expressions.

To summarize, this thesis will investigate infants' perception of observed social interactions by using behavioral (preferential looking) and neurophysiological measures (ERPs and EMG), investigating infants' processing of positive and negative social signals (prosocial and antisocial actions; happy and angry gestures), and whether their mother touch may modulate infants' attention toward them.

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Chapter 1.

Infants' perception of dynamic prosocial and antisocial events: An ERP study[1]

From early in life, infants are attuned to certain perceptual and social features that guide their attention within a complex environment. Newborn infants show a preference toward individuals displaying more attractive facial features (Quinn, Kelly, Lee, Pascalis & Slater, 2008; Slater, Quinn, Hayes, & Brown, 2000) and for those who make direct instead of averted gaze (Farroni, Csibra, Simion & Johnson, 2002). Around 6 months of age, infants appear to be drawn more towards people who are expressing more negative over positive emotions (Vaish, Grossmann & Woodward, 2008). Overall, these results indicate that infants rely on multiple perceptual and social cues when they interact with other people.

Over the past several years, there has been a growing interest in how preverbal infants evaluate various socio-moral situations. At 3 months of age, infants have been shown to look longer toward individuals who act in a prosocial manner over those who behave antisocially to another person (Hamlin, Wynn & Bloom, 2010). In a similar way, by the age of 6 months, infants begin to approach individuals who behave prosocially, and actively avoid those who behave antisocially (Hamlin & Wynn, 2011; Van de Vondervoort & Hamlin, 2018). Once infants are older, their evaluations of socio-moral situations evolve into more mature prosocial behaviors, so that they help others when needed (Warneken & Tomasello, 2009), respond empathically to others and behave accordingly (Nichols, Svetlova, & Brownell, 2012), and start to develop the idea of fairness and altruism (Schmidt & Sommerville, 2011).

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[1] Parts of this chapter, including data, results, and some parts of the text are already reported in a submitted manuscript paper by Licht, V., Addabbo, M., Nava, E., & Turati. C. Neural signatures to prosocial and antisocial events in young infants.

Recently, two studies have begun to explore the neural correlates of infants' moral evaluation abilities, but only one of them involved infants in the first year of life. Specifically, Gredebäck and colleagues (2015) used Event-Related Potentials (ERPs) with 6-month-old infants who watched prosocial and antisocial characters and found increased amplitude of the P400 component in response to the prosocial character, particularly over the posterior temporal areas. Typically, the P400 component is considered to be an index of the processing of the social aspects of a stimulus, including emotional features (Leppänen, Moulson, Vogel-Farley, & Nelson, 2007) and goal-directed actions (Bakker, Daum, Handl, & Gredebäck, 2015).

A second study (Cowell & Decety, 2015a) investigated whether characteristics of 12–24-month-old infants' neural activity could predict their inclination toward prosocial interactions when observing cartoon characters in a preferential paradigm. They revealed that the NC, a mid-latency component found around 300-500 ms and generally indexing attentional response to salient stimuli, had a greater amplitude to the prosocial interaction, consistently with behavioral data showing a preference for the prosocial character.

The divergent results obtained in the two studies mentioned above (P400 in the study by Gredebäck and colleagues (2015); NC in the study by Cowell & Decety (2015a)) might be a consequence of different ages tested, as well as methodological differences. It needs to be mentioned that Gredebäck et al. (2015) used a familiarization phase to the prosocial and antisocial scenes and analyzed 6-month-olds' ERP responses to the still image of the character who performed the prosocial or antisocial action. Differently, Cowell & Decety (2015a) measured ERPs that are elicited while 12–24-month-olds watched two characters interact dynamically in prosocial or antisocial scenes. The sole difference related to the presentation of static or dynamic stimuli could have elicited different ERPs' components, as usually dynamic stimuli tend to capture infants' attention more than still stimuli (Quadrelli, Conte, Macchi Cassia, & Turati, 2019).

Furthermore, other neurophysiological studies observed that, with age, the evaluation of socio-moral situations become more complex and, as a result, involve various other neural circuits and additional underlying cognitive processes. For instance, at 14 months of age, Paulus and colleagues (2013) found distinct neural patterns related to different prosocial behaviors, such as helping and comforting. Additionally, a study with 3–5-year-olds reported changes in the LPP (i.e., a measure of cognitive processing of social stimuli), the N2 (i.e., a measure of mismatch detection), and Early Posterior Negativity (EPN, i.e., a measure of automatic attention) when observing scenes depicting helping or harming actions (Cowell & Decety 2015b).

The current study sought to investigate 5-months-old infants' neural responses to a prosocial and antisocial scene, particularly aiming at examining four ERP components, which have been documented to be elicited in processing prosocial events in infants and children (Cowell & Decety, 2015a; Gredebäck et al., 2015). Specifically, focusing on the N290 and P400 over occipito-temporal locations, and the NC and LPP over the central electrode locations. It is important to mention that we measured ERPs elicited with dynamic prosocial and antisocial interactions, instead of a still image of the character who performed the prosocial and antisocial actions, as we reasoned that the prosocial and antisocial action would be more salient for infants and maybe easier to process than the sole static character (Quadrelli et al., 2019). Additionally, we verified whether the infant's brain activity could predict or was associated with their fondness to prosocial agents, measured through a manual choice task (see Hamlin, Wynn, & Bloom, 2007).

Methods

Participants

The final sample consisted of 19 full-term, healthy 5- to 6-month-old participants (10 males, M age = 169.5 days, SD = 14.4 days, range = 144-189 days). The sample size is similar to other EEG studies investigating ERPs with infants this age (e.g., N=18 in Quadrelli et al., 2019; N=14 in Gredebäck et al., 2015; de Haan, Belsky, Reid, Volein, & Johnson, 2004). An additional 30 infants were tested but excluded due to fussiness (N = 9), or excessive artifacts (N = 21). Proportion of excluded infants was also similar to previous EEG studies with the infant population (de Haan et al., 2004; Stets, Stahl, & Reid, 2012). The age range was selected based on Gredebäck et al. (2015) (6-month-olds), all participants were full term and healthy. The procedure was carried out in accordance with The Declaration of Helsinki (BMJ 1991; 302: 1194) for experiments involving humans and was approved by the Ethical Committee of the University of Bicocca-Milano. All parents completed a written informed consent form before the beginning of the study.

Stimuli

The study consisted of a familiarization and a test phase. Stimuli of the familiarization phase were ~20s videos similar to the ones described in the study of Hamlin and Wynn (2011), in which one puppet struggles to open a box and is either helped (i.e., prosocial event) or hindered (i.e., antisocial event) by another puppet to achieve its goal (see Fig. 1). The puppets were an orange tiger with black stripes, a brown monkey, and a grey elephant with neutral expressions. In the first 13 seconds of the videos, the elephant attempted to open a transparent box containing some toys, and, starting around second 15, the tiger or monkey performed the prosocial (helping the elephant to open the box) or the antisocial action (hindering the opening of the box). The videos had the background darkened to eliminate any possible shadows or additional distractions of the background movement. Half of the participants saw the tiger helping and the monkey hindering the box opening action. The other half of the participants observed the reversed roles. The videos were flipped during the presentation at random points so that each puppet was beginning their prosocial or antisocial action from each side of the screen, and this was done for both the familiarization and test phase. The duration of each familiarization video was ~20 seconds.

Stimuli of the test phase consisted of four frames extrapolated from the original familiarization videos. A single test trial consisted of four still frames: the first frame depicted the pro or antisocial character near the box kept open by the elephant, the second frame depicted the pro or antisocial character turning towards the box and touching it, the third frame showed the pro or antisocial character moving the lid of the box (opening vs. closing), and the last frame showed the character either closing the box for the antisocial action or completely opening the box for the prosocial action. The 4 frames were shown in rapid succession: the first frame was presented for 0.5 s, the second and third frame for 0.3 s, and the fourth frame for 0.5 s. Overall, the total duration of each trial was 1.6 s. Thus, the 4 frames in succession gave the illusion of the unfolding of the prosocial and antisocial action. The use of 4 still frames allowed us to control for the speed of movement. In addition, stimuli were also equalized for luminance, which did not differ between prosocial ($M = 36.6$; $SD = 4.5$) and antisocial ($M = 35.1$; $SD = 4.1$) stimuli (Mann–Whitney test, $p > .11$).

A manual task followed the EEG recording, in which infants were presented with the prosocial and antisocial puppet and chose the one they preferred.

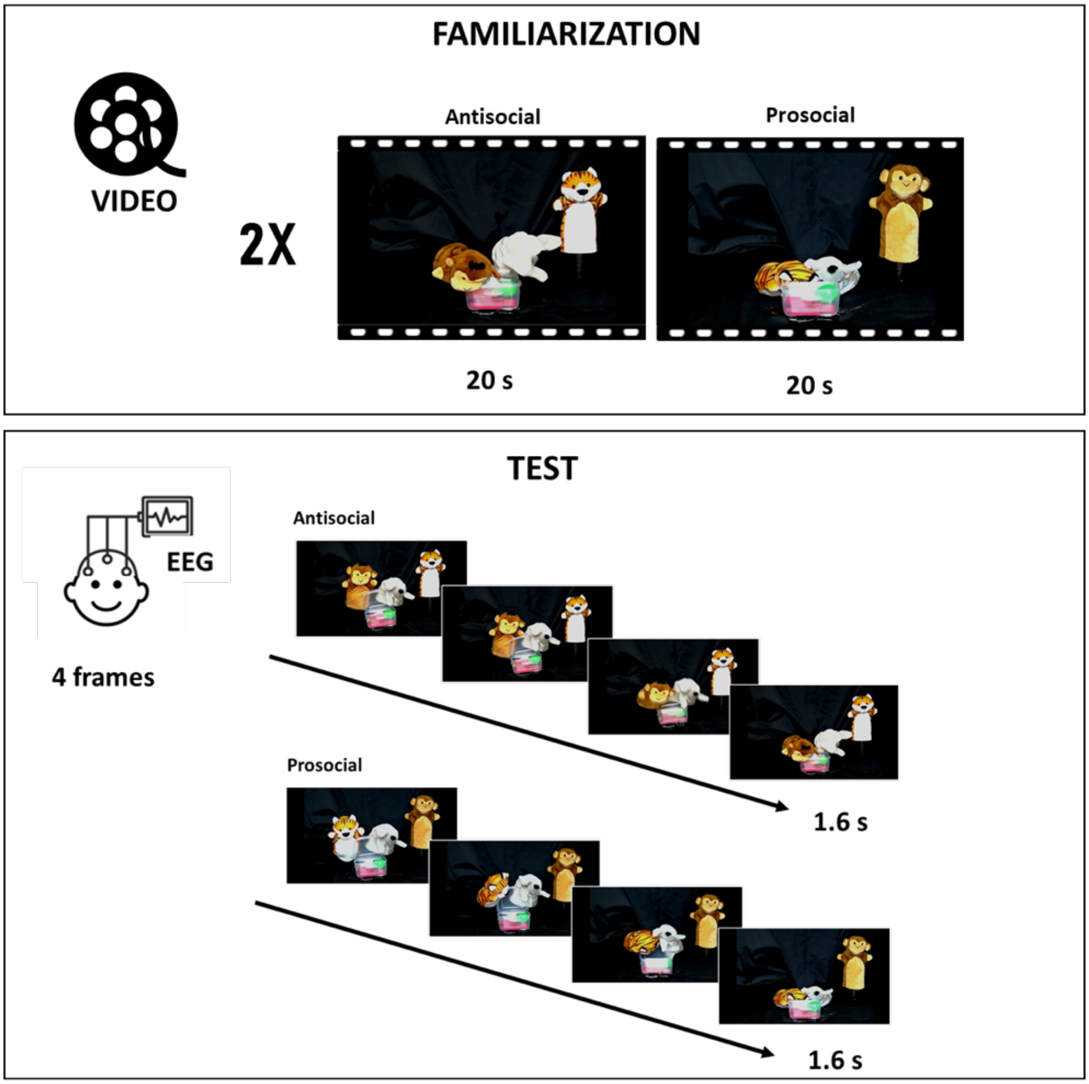

Figure 1. Schematic depiction of stimuli presentation. During the familiarization phase, 4 videos were presented (2 antisocial and 2 prosocial). During the test phase, neural activity was measured during the presentation of 60 video clips (30 antisocial and 30 prosocial), comprised of 4 still frames.

Procedure

The experiment took place in a dark, electrically shielded cabin, in which infants were sat on their parent's lap, roughly 60cm from a 24-inch monitor. The circumference of the infant's head was measured, and the EEG net was then placed on the infant's head. Once the cap was properly fitted, the impedance was measured and adjusted to be lower than 50 KΩ. Parents were instructed to remain as still and quiet as possible to avoid any audio or movement artifacts from the parent during the experimental recording. In the familiarization phase, infants were shown four 20 seconds videos depicting two prosocial and two antisocial events that lasted approximately 80 seconds in total. Stimuli were presented using E-Prime software v2.0 (Psychology Software Tools Inc., Pittsburgh, PA). To be included in the analyses, infants had to watch at least one video depicting the prosocial and antisocial scene, and they had to watch at least one out of three actions in which the elephant struggled to open the box followed by the whole prosocial/antisocial action.

The test phase comprised overall 60 test trials (30 prosocial and 30 antisocial events). Each video clip was presented in a pseudorandomized order and separated by a 1second inter-trial interval (ITI). The testing ended once the infant completed the 60 test trials, began to become fussy or stopped looking at the screen. The entire duration of the EEG recording was approximately 4 mins.

Immediately after the EEG testing, participants had their EEG cap removed and were placed in a bumbo seat to begin the manual choice task. Parents were seated apart and instructed not to interact with the infant or look at the puppets for the duration of the task to avoid influencing the infant's decision or distracting them from the task. At the beginning of the manual choice task, the experimenter placed the antisocial and prosocial puppets in front of the infant (about 50cm) and asked the infant which one they wanted to play with. The experimenter performing the task was unaware of which of the two puppets was the pro- or the antisocial character and was instructed not to influence the infant's choice. For example, he/she was not allowed to look at one of the two puppets. Once the infant looked at both puppets, the experimenter moved the puppets within arm's reach of the infant and waited for the infant to reach for one puppet. If within 30 s no reaching movement was performed, the task was concluded (Hamlin et al., 2007; Hamlin et al., 2010). The task was both coded online and offline, and the left/right position of the prosocial and antisocial puppet was counterbalanced across participants.

EEG Recording and Processing

The electroencephalogram (EEG) was recorded with a 128- electrode HydroCel Geodesic Sensor Net (Electrical Geodesic Ine., Eugene, OR). EEG recording was continuous and referenced to the central electrode (Cz). Signals were amplified using the EGI NetAmps 300 amplifier with a sampling rate of 500Hz and an online band-pass filter of .1-100Hz. Impedance was checked prior to the beginning of the testing session and accepted if lower than 50 KΩ. EEG data was processed offline using NetStation 4.5 (Electrical Geodesic, Eugene, OR). The continuous signals were segmented into 1600 ms epochs post-stimulus onset, with a baseline period beginning 100 ms before the onsets. The signal was then band-pass filtered at .3-30 Hz and baseline corrected using mean voltage during the 100 ms pre-stimulus periods. Single channels were automatically rejected with a signal exceeding ±200 μV, and the remaining artefacts (i.e., eye-blinks, saccades) were manually discarded. When 15% of channels (N =18) or more were discarded, the entire trial was excluded from the additional analysis. Individual channels containing artifacts were replaced using spherical spline interpolation. For each participant, average waveforms were generated within each experimental condition. The mean number of trials was 9 (min 5-max 15) for the prosocial condition and 8 (min 5-max 14) for the antisocial condition, with no differences across conditions, $t(14) = 1.69$, $p = 0.17$.

For the grand average of waveforms, three clusters were looked at for analysis: central cluster (Left: 36, 37, 41, 42, 47; Right: 87, 93, 98, 104, 103), temporal cluster (Left: 57, 58, 59, 64; Right: 91, 95, 96, 100), and occipital cluster (Left: 65, 66, 69, 70, 71, 74; Right: 76, 82, 83, 84, 89, 90). We focused on four specific ERP components: the temporo-occipital N290 (240-340ms) and P400 (360-600ms); the central NC (350-600ms) and LPP (650-950ms). Time windows and electrode clusters were chosen based on visual inspection and were similar to the ones used in previous studies with infants (Addabbo, Bolognini, & Turati, 2021; Gredebäck et al., 2015; Xie, McCormick, Westerlund, Bowman, & Nelson, 2019). Each component's mean amplitude (μV) values were extracted and used for statistical analysis.

Results

Familiarization Phase

During the familiarization phase, the mean looking time to the prosocial action was 15.1 sec (SD = 3.26) and 16 sec (SD = 2.34) to the antisocial action. No difference was found between looking times to prosocial and antisocial videos ($t\ (18) = -1.25$, $p = .227$).

N290 (240-340 ms)/ P400 (360-600)

A rmANOVA was conducted on the mean amplitude of the N290 and P400 with Electrode Cluster (Occipital, Temporal), Lateralization (Right, Left), and Condition (Prosocial, Antisocial) as within-subject factors.

Results over the N290 showed a main effect of Laterization, $F(1,18) = 4.63$, $p = .045$; $\eta p^2 = .205$, as the N290 was larger over the right (M = 9.47; SD = 10.2) compared to the left hemisphere (M = 5.96; SD = 9.39). No other main effect or interaction reached significance (all $ps > .062$).

Results over the P400 showed a significant main effect of Lateralization, $F(1,18) = 5.23$, $p = .035$, $\eta p^2 = .049$. Further, a lateralization x electrode cluster interaction emerged, $F(1,18) = 9.97$, *p* =.005, ηp^2 = .023. No other main effect or interaction reached significance (all *ps* > .18). Posthoc t-tests (Tukey corrected) revealed that, in the left hemisphere, the P400 amplitude was greater in the occipital (*M* = 10.9 µV, *SD* = 8.26, *t (18)* = 2.83, *p* = .05) compared to the temporal cluster (*M* = 6.46 *µV*, *SD* = 9.07), *t (18)* = -2.84, *p* = .048. No other comparison reached significance (all *ps* > .10).

Nc (350-600 ms)

A rmANOVA was conducted on the mean amplitude of the central electrodes for Nc with Lateralization (Right, Left) and Condition (Prosocial, Antisocial) as within-subject factors. Results showed a main effect of Condition, *F(1,18)* = 5.24, *p* = .034, ηp^2 = .226. There was a greater amplitude to the antisocial condition (*M* =-5.68 µV, *SD* = 5.83) compared to the prosocial condition (*M* = -2.17 µV, *SD* = 5.58). No other main effects or interaction emerged (all *ps* > .86).

LPP (650- 1200 ms)

A rmANOVA was conducted on the mean amplitude of the central electrodes of the LPP with Lateralization (Right, Left) and Condition (Prosocial, Antisocial) as within-subject factors. Results over the LPP showed a main effect of Condition, *F(1,18)* = 4.99, *p* =.038; ηp^2 = .217. The amplitude of the LPP was greater in response to the prosocial (*M* = 4.02 µV, *SD* = 6.86) compared to the antisocial (*M* = .56 µV, *SD* = 5.61) scene. No other main effect or interaction reached significance (all *ps* > .35).

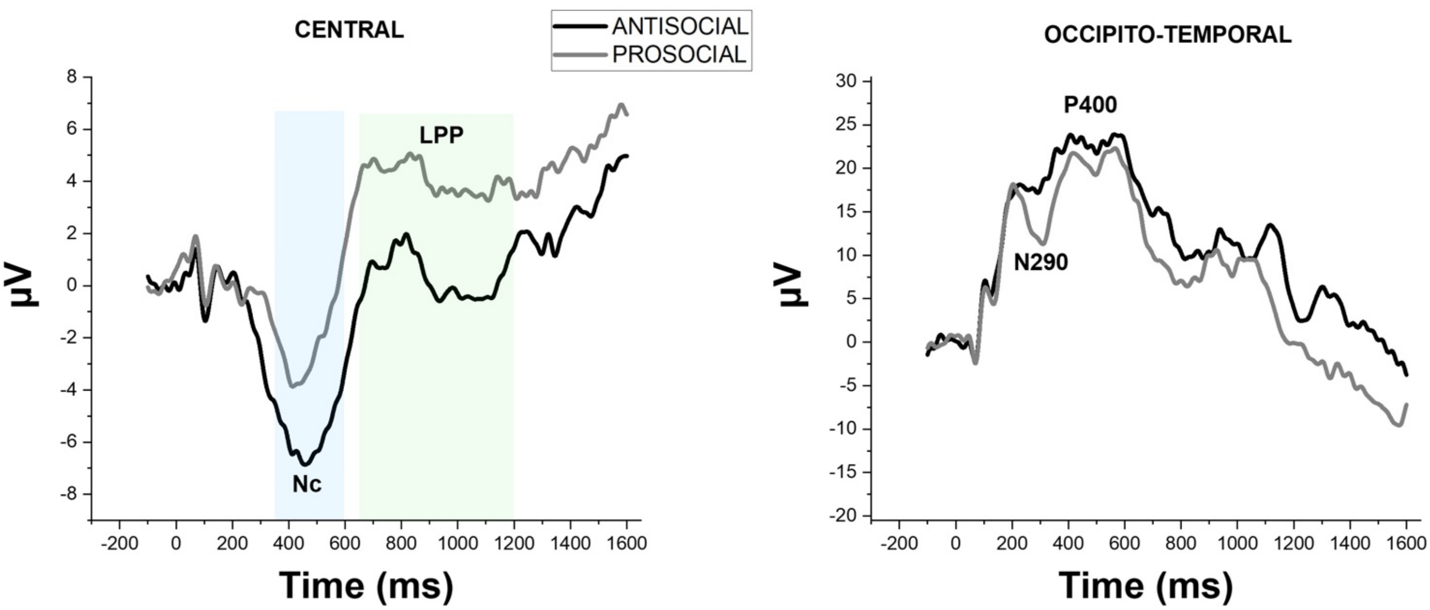

Figure 2. Average waveforms elicited in response to Prosocial and Antisocial actions in each the central (left panel) and occipito-temporal (right panel) cluster. The shaded areas indicate the time windows of the ERP components where significant differential activity was found.

Behavior Results: Manual Choice Task

A binomial test was used to assess infants' manual preference. However, no difference was found (p = 0.82), in that N = 8 infants chose the prosocial character, N = 9 infants chose the antisocial character, and N = 2 infants made no choice.

Discussion

While several studies, using behavioral methods, have shown that, by 6 months of age, infants avoid individuals who act antisocially while approaching those who act more prosocially (Hamlin & Wynn, 2011; Margoni & Surian, 2018; Van de Vondervoort & Hamlin, 2018), the neural underpinnings of infants' inclination toward prosociality is poorly investigated. This current study provides supporting evidence that infants as young as 5-months-old can discriminate prosocial and antisocial events. Moreover, this study showed that two ERP components differentiate moral scenes, showing larger NC amplitude for antisocial scenes and larger LPP component elicited by the prosocial events.

The larger NC elicited during the observation of antisocial scenes suggests that infants' attention was more attracted to the antisocial events than prosocial ones, since the NC has been seen as an index of attention allocation (de Haan et al., 2004; Cowell & Decety, 2015 a & b; Leppänen et al., 2007; Richards, 2003). Previous studies have reported that large negative NC amplitudes were observed when infants are shown fearful facial expressions over happy ones (Leppänen et al., 2007; de Haan et al., 2004), angry voices over happy (Grossmann, Striano, & Friederici, 2005), and fearful over happy body expressions (Krol, Rajhans, Missana, & Grossmann, 2015). Additionally, larger NC activation was found while watching harming actions (poke in the eye) over neutral actions (touch on eyebrow) at 6 months of age (Addabbo, Bolognini, & Turati, 2021). Although the stimuli used in this study are not overtly emotionally, we could say that they might arise an emotional, positive or negative, response.

The LPP is typically considered as a social component, that appears in both children (Cheng, Chen & Decety, 2014; Cowell & Decety, 2015 a &b) and adult brain (Yoder & Decety, 2014), is associated with the cognitive reappraisal of a social situation. The results found over the NC (mid- latency) and the LPP are in line with the study by Cowell & Decety (2015b), who found larger amplitude of the N2 ERP component to harmful actions and larger amplitude of the central LPP to the helping actions. Interestingly, in that study they found that larger activation of the LPP with 3–5-year-olds predicted more prosocial behavior (i.e., sharing). In line with this study, we found that prosocial scenes trigger an increase of cognitive resources involved in sociomoral evaluation.

We did not observe differing activity of early posterior ERP components in infants, such as N290, that indicates a quick automatic processing of social situations and could still be underdeveloped at 5-6 months of age.

Although Gredebäck and colleagues (2015) tested infants of similar age to our study, results obtained do not overlap, as we did not see any modulation of the P400 when observing the prosocial scenes. Yet, as already mentioned, the design of the two studies differed in one important aspect, as Gredeback and colleagues (2015) showed infants still images of the character who performed the prosocial or antisocial action, while we presented infants 4 frames in rapid succession that gave the impression of a prosocial or antisocial interaction unfolding. Previous studies have suggested that motion assists perception in infants in different areas (e.g., emotion processing), demonstrating better performance during testing with dynamic stimuli (Heck, Hock, White, Jubran, & Bhatt, 2016). Therefore, it is likely that our dynamic stimuli elicited a differentiated responses of targeted ERP components (e.g., NC, LPP), assisting the infants' processing of the prosocial and antisocial actions. Additionally, the presentation of prosocial and antisocial actions, instead of the character that performed the action, may help infants processing the moral events.

Lastly, as for our behavioral results, we were not able to replicate findings from previous studies (e.g., Hamlin & Wynn, 2011) that demonstrated infants' preference for the prosocial characters through a manual choice task with 5-month-olds. It is important to note that past studies also had difficulties replicating these findings, and even in older infants the helper over hinderer preference did not clearly arise (Salvadori et al., 2015; Scarf, Imuta, Colombo, & Hayne, 2012). This divergence could be due to the important methodological differences of the experiments. In particular, our study did not use a traditional habituation paradigm since we were interested in recording the ERPs.

Our study has some limitations. First, our stimuli are novel in showing a dynamic prosocial and antisocial interaction. Considering that we only tested an age range of 5 to 6 months old, further studies would be necessary to have a more accurate developmental trajectory of the neurophysiological correlates of the perception of prosocial and antisocial dynamic actions. Secondly, by only testing one age range, we were limited in our analysis of the behavioral preference data: studies on older infants might find a link between infants' behavioral preference and amplitude of ERP components. Lastly, another possible limitation is the attrition rate (around 60% of sample), this opens the question to the suitability of the paradigm in this population. Nonetheless, high attrition rate is a common factor in electrophysiological measures, specifically electroencephalographic, with mainly visual stimuli (Stets et al., 2012).

In conclusion, the results of our study showed that the infants' brains may be attuned to processing moral situations, as shown by the modulation of specific ERP components to the processing of prosocial and antisocial situations. Overall, the antisocial actions held infants' attention the most, whilst prosocial actions involved more cognitive reflection during processing. This further grows our knowledge of infants' processing of sociomoral interactions. Future studies might further clarify the relative contribution of the different neural mechanisms involved in infants processing of moral situations. Additionally, this study has only looked at helping interactions, another future study could take into account other sociomoral behaviors like sharing or comforting to have a more complete understanding of similarities and difference of neurophysiological mechanisms involved in the processing them.

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Chapter 2.

Infants' facial EMG response to the observation of emotional interpersonal touch[1]

Touch is an essential part of communication, and through touch, we can convey emotional and affective states, such as anger, fear, disgust, love, and sympathy. Through the way touch is performed, adults are capable to differentiate emotional expressions with about the same range of accuracy of facial and voice emotion expression (Hertenstein, Keltner, App, Bulleit, & Jaskolka, 2006; Hertenstein, Holmes, McCullough, & Keltner, 2009). The velocity of the touch (fast or slow), the intensity (amount of pressure applied), the action of the touch (a stroke or a pat) can lead to the expression of a different emotion (Hertenstein et al., 2009). Within this wide range, a light, gentle slow stroke or affective touch is linked to increased firing of specific tactile fibers called C tactile afferents and gives origin to a pleasant tactile sensation (McGlone, Wessberg, & Olausson, 2014; Cascio, Moore, & McGlone, 2019; Löken, Wessberg, McGlone, & Olausson, 2009). Early in life, affective touch is considered important, and known to promote social bonding (Field, 2014).

Evidence of adult participants shows touching gestures are mediated by a multi-sensory-motor system that encompasses somatic and visual elements (Bolognini, Rossetti, Maravita, & Miniussi, 2011), thus pairing visual observation of touch with our perception of touch and suggesting the involvement of a "Tactile- Mirror system" (Bolognini et al., 2011; Bolognini, Rossetti, Convento, & Vallar, 2013). Previous studies have found that observing touch on someone else's body activates brain areas that are also activated during direct tactile perception

[1] Parts of this chapter, including data, results, and some parts of the text included are reported in an unpublished manuscript by Addabbo, M., Licht, V., & Turati, C. Infants' EMG facial responses to the sight of emotional interpersonal touch.

(physical contact) (Serino, Pizzoferrato, & Ladavas, 2008). In other words, observing others being touched gives rise to the activation in the observer of the somatosensory area and an empathic response (Bolognini et al., 2013). Specifically, the primary somatosensory cortex (S1) shows increased activity when one observes affective expressions through touch (Bolognini et al., 2013; Keyser, Kaas, & Gazzola, 2010). Furthermore, an electromyographic (EMG) study has shown modulation of the activation of facial muscles in response to both perception and observation of pleasant and non-pleasant touches. A pleasant slow-moving stroke (3 cm/s) results in a relaxation of the corrugator supercilii (CS) muscles, while a less pleasant fast-moving stroke (30 cm/s) determines an increased activation of CS (Mayo, Lindé, Olausson, Heilig, & Morrison 2018).

Touch is a modality that is experienced very early in life and that infants are sensitive to. Even at 3rd trimester, fetuses show a wide range of responses to tactile stimulation provided by their mother (Marx & Nagy, 2017). Newborns can even differentiate between visually observed touching and non-touching gestures, and, by 3 months of life, they begin to manifest a preference for touching gestures over non-touching gestures (Addabbo et al., 2015). Several electrophysiological studies have reported that infants engage their somatosensory system while watching others being touched (Addabbo, Quadrelli, Bolognini, Nava, & Turati, 2020a; Meltzoff, Ramírez, Saby, Larson, Taulu, & Marshall, 2018; Rigato, Banissy, Romanska, Thomas, van Velzen, & Bremner, 2019). A magnetoencephalographic (MEG) study found that 7-month-olds, either being touched (hand or foot) or watching someone being touched, showed the same activations in the corresponding somatosensory areas (Meltzoff et al., 2018). Additionally, an electroencephalographic (EEG) mu rhythm study with 8-month-olds found a desynchronization over the somatosensory sites responding to both the touch and observed touch condition, which meant that infants showed an experience of being touched while only watching another person being touched (Addabbo et al., 2020a). Thus, infants seem to be able to detect the connection between a touch on their body and on others' bodies.

Touch is a main form of communication between parents and infants for reassurance and affection (Field, 2010; Cascio, 2010; Della Longa, Gliga, & Farroni, 2019). Whether it's through a hug or a caress, touch transfers important information to the infant either with direct contact or by observing others. The question remains if infants can detect emotional content from observed interpersonal contact?

Early in development, infants can perceive emotional signals, either by facial expressions, voices, body posture, or kinematics (Nava, Romano, Grassi, & Turati, 2016; Addabbo, Vacaru, Meyer, & Hunnius, 2020b; Crespo-Llado, Vanderwert, & Geangu, 2018; Missana, Atkinson, & Grossmann, 2015). Additionally, viewing such emotional stimuli elicits facial responses congruent to the emotional signals shown (Addabbo et al., 2020b; Kaiser, Crespo-Llado, Turati, & Geangu, 2017; Datyner, Henry, & Richmond, 2017). Recent EMG studies have found that infants responded with matching facial responses to happy and fearful faces, but not to angry faces at 7 months (Kaiser et al., 2017; Datyner et al., 2017). Specifically, infants that observed happy facial expressions had increased activity in their zygomaticus major (ZM) muscle, which is typically active when people smile, while fearful facial expressions evoked higher activity of the frontalis muscle, located on the forehead. Another EMG study investigated 11-month-olds' ability to detect affective content conveyed by kinematic information (grabbing a toy off the table and placing it down, either action with a happy or angry connotation): results showed that infants' facial EMG reactions were congruent to the affective information provided by the observed kinematic action. Particularly, higher activation of infants' ZM was recorded in response to happy kinematics (grabbing and placing the toy down with pleasant or gentle motion) and higher activation of infants' CS was elicited in response to angry kinematics (grabbing and placing a toy down with an angry motion) (Addabbo et al., 2020b). This study demonstrated that infants are sensitive and can extract affective content from kinematic information. Nonetheless, the question remains open about whether infants are sensitive to the emotional content of interpersonal touch.

The goal of the current study was to further explore the affective sensitivity of 11-month-old infants to the observation of emotional information expressed by interpersonal touch. We measured facial EMG reaction to the observation of positive (caress) and negative (scratches) interpersonal touch. The 11-month-old age was picked based on a previous study using the same age showing that infants responded with facial expressions that matched angry or happy information conveyed by kinematics (Addabbo et al., 2020b). Additionally, previous studies have found that younger infants (i.e., 7-month-olds) reacted with congruent facial expressions to happy and fearful faces, but not to angry faces, showing that infants EMG facial reactions to emotional stimuli can be reliably recorded by 7 months and before the end of the first year (Kaiser et al., 2017; Datyner et al., 2017). The EMG recording allowed us not only to understand whether infants are capable to discriminate and recognize the perceived positive and negative affective interactions, but also to discern the affective (positive or negative) direction of their reaction. In this study, infants watched videos displaying an actress receiving a caress or a scratch on their arm, while EMG facial activity from infants' smiling (ZM) and frowning (CS) was measured. This is aligned with past EMG studies that also investigated facial responses to emotional stimuli (Addabbo et al., 2019; Datyner et al., 2017; Kaiser et al., 2017). We anticipate a significant activation of the ZM and not the CS in response to the observation of affective touch (Caresses), while an increased activity of the CS but not the ZM is expected in the non-affective touch condition (scratches).

To take into consideration individual differences, the Social Touch Questionnaire (STQ) (Wilhelm, Kochar, Roth, & Gross, 2001), which evaluated the infant's attitude to social touch, was completed by the mother. Attitude towards touch varies widely: for instance, social anxiety is typically accompanied with higher avoidance of social touch (Wilhelm et al., 2001). Additionally, positive attitudes concerning touch is a vital element in social competence for young children and their development (Jones & Brown, 1996). Previous studies showed that an infant's temperament can alter the infant's visual and neural responses to emotional stimuli (de Haan, Belsky, Reid, Volein, & Johnson, 2004). So, we hypothesize that comfortability with social touch might affect how infants respond to the observed negative tactile experiences that involve other individuals.

Method

Participants

Eighteen 11-month-old infants recruited from a database of volunteer families of University of Milan- Bicocca were included in the final sample (9 girls; mean age: 353 days, range: 330-364 days). 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. Twenty additional infants were tested but not included in the final analysis due to fussiness (n = 8), not accepting electrodes on their face (n = 6), or excessive movement artifacts in the signal (n = 6). This high dropout rate is typical in EMG studies with infants and children populations (Addabbo et al., 2020b; Isomura & Nakano, 2016). Furthermore, the age group and sample size are similar to one reported in the study by Addabbo et al. (2020b), where differences in EMG facial responses to emotional kinematic movements were reliably found. Parents were informed about the procedure and gave their written consent to their child's participation. The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki (BMJ 1991; 302: 1194), and the research was approved by the Ethics Committee of the University of Milan- Bicocca (Protocol number: 236).

Stimuli

The visual stimuli consisted of 8 colored videos showing a female actress delivering a tactile stimulation on the arm of another actress. In the Caress condition, the video displayed an actress delivering a stroke on the recipient's arm. In the Scratch condition, the actress delivered a scratch on the recipient's arm (see Figure 1). The faces of the actresses were not visible, and their bodies were shown one next to the other. For each condition, 4 different versions of the caress and scratch videos were created by asking 4 different actresses to deliver the two types of touches (caress/scratch) on the arm of the actress placed in front of them. In all videos, caresses and scratches were performed on the right arm of the recipient, from the shoulder to the wrist. The agent of the touch was on the left, and the recipient of the touch was placed on the right. All the videos lasted 2000 ms. The onset of the action (i.e., the time at which the hand started moving on the arm) and offsets (the time at which the hand stopped moving) were the same in all the videos. Stimuli were validated by 20 adults (11 females, mean age = 26.6 years, SD = 5.1), who were asked to judge on a 7 point Likert-scale: 1) whether the perceived touch was affective or not affective, from 'not affective at all' (-3) to 'very affective' (+3); 2) the valence of the touch, from 'very negative' (-3) to 'very positive' (+3), and 3) the pleasantness of the touch, from 'very unpleasant' (-3) to 'very pleasant' (+3). Paired sample t-tests revealed that the caress was rated as more affective (Mean, M = 1.5, Standard Deviation, SD = 0.7) than the scratch (M = - 1.5, SD =

1.6) (t(19) = 7.1, p < .001). The caress was also rated as more positive (M = 1.7, SD = 0.47) than the scratch (M = - 1.7, SD = 0.71) (t(19) = 15.4, p < .001), and more pleasant (M = 1.5, SD = 0.6) than the scratch (M = - 1.4, SD = 1.1) (t(19) = 8.4, p < .001).

Procedure

The infant's face was cleaned with a baby wipe before they were positioned on the parent's lap 60 cm from a 24" stimulus presentation monitor (1920 X 1080 pixel resolution). The infant was recorded by a video camera installed above the screen. The video served to code infants' attention and face/body movements offline. A cartoon was displayed on the screen to keep the infant calm and distracted while the experimenter placed the electrodes on the infant's face. The presentation of the stimuli was pseudo-randomized (the same emotion could not be displayed more than twice in a row). There was no restriction in the maximum number of trials shown, and the experiment ended after the infant stopped looking 5 trials in a row. Each trial began with a colored fixation cross displayed on the screen for a variable amount of time ranging between 1100 and 1500 ms to attract the infant's attention to the center of the screen. In particular, the fixation completed two rotations during the first 500 ms of presentation. A brief beep accompanied each rotation. Then, the fixation cross remained still for a variable amount of time, ranging between 600 and 1000 ms, and was followed by the experimental stimulus (2000 ms in duration).

EMG Recording and Data Reduction

Facial electromyographic activity was measured with a Digitimer electromyograph. Surface cup electrodes (reusable 4 mm Ag/AgCl) were placed over the *zygomaticus major* muscle and the *corrugator supercilii* following standard bipolar electrode placement procedures

(Tassinary, Cacioppo, & Geen, 1989). On each muscle of the left side of the face, two electrodes were placed at a distance of 1 cm center to center, parallel to the length of the muscle (Cacioppo et al., 1986; Fridlund & Cacioppo, 1986). The ground electrode was placed on the forehead below the hairline. The EMG signal was recorded at a sampling rate of 1000 Hz, amplified (gain 1000), and filtered (band-pass: 10–1.000 Hz). The EMG signal was then pre-processed off-line using EEGLab (Delorme & Makeig, 2004). The signal was first bandpass filtered with a high pass frequency of 20 Hz and a low pass frequency of 500 Hz (Van Boxtel, 2001; Van Boxtel, 2010). The signal was then rectified. A visual artifact rejection based on visual inspection of the EMG signal was then conducted by an experimenter blind to the experimental conditions. Trials containing baseline noise or artifacts due to the movement of the wires or detachment of the electrodes were discarded. Videos were also coded offline to exclude the trials in which the infant did not attend to the stimuli or performed facial movements that could contaminate the target muscles signal, such as vocalizing, chewing on their hand, yawning, or crying. The mean number of trials across conditions was 13.4 (min 8-max 21) for the caress condition and 11.4 (min 7-max 24) for the scratch condition.

Average activation for each 100 ms interval post-stimulus onset was calculated. Each post-stimulus 100 ms time bin was then transformed into z-scores within participants and muscle sites (using the grand average mean and standard deviation) and then baseline-corrected by subtracting the average amplitude of the 500 ms pre-stimulus interval (Kaiser et al., 2017; Addabbo, Vacaru, van Schaik, & Hunnius, 2019). As in previous studies (Addabbo et al., 2019; Kaiser et al., 2017), we expected greater activity of the ZM compared to the CS in response to Caresses and greater activity of the CS compared to the ZM in response to Scratches.

The Social Touch Questionnaire

After the testing sessions, the mother filled out the Social Touch Questionnaire (STQ) (Wilhelm, Kochar, Roth, & Gross, 2001) in a version created in the third-party perspective to allow mothers to self-report their infant's attitude towards social touch. The questionnaire provides a sample of behaviors and attitudes towards the social touch and differentiates between social touch in public vs. in a private place, with someone we know vs. strangers, and received vs. delivered touch. Mothers were asked to state to what extent 15 statements were true using a 4-point Likert scale (0=not at all, 1=slightly, 2=moderately, 3=very, 4=extremely). Five statements (items 8, 9, 16, 17, 20) were excluded from the original version of the questionnaire, being not applicable to the age of the participants (e.g., I'd feel uncomfortable if a professor touched me on the shoulder in public) or related to intimate affection (e.g., I feel disgusted when I see public displays of intimate affection). Two statements were slightly changed to adapt them to infants' experience: In statement 2, 'I feel uncomfortable when someone I don't know very well hugs me' was replaced with 'My child feels uncomfortable when someone he doesn't know very well holds him in the arms,' while in statement 4, 'I get nervous when an acquaintance keeps holding my hand after a handshake' was replaced with 'My child gets nervous when an acquaintance keeps touching him.' The total number of items was 15. Thus, the total score ranged between 0 (lowest avoidance of social touch) to 60 (most avoidance of social touch). The questionnaire was translated into Italian. The back-translation was performed by one translator whose native language is English.

Results

A rmANOVA on Z-transformed data with Emotion (Caress, Scratch), Muscle (ZM, CS) and time window (0-500, 500-1000, 1000-1500, 1500-2000) as within-subject factors revealed a significant main effect of Emotion ($F(1,17) = 6.46$; $p = .02$, $\eta_p 2 = .27$). Overall, greater EMG activation was found during the observation of the caress ($M = 0.81$; $SD = 0.43$) compared to the scratch ($M = 0.09$; $SD = 0.95$). The analysis also revealed a significant effect of Time Window ($F(3,51) = 3.77$; $p = .02$, $\eta_p 2 = .18$). Infants' EMG activity was greater in the 1500-2000 time window ($M = 0.44$; $SD = 0.32$) compared to the 0-500 time window ($M = 0.12$; $SD = 0.25$), $t(17) = 3.27$; $p = .004$ and to the 500-1000 time window ($M = 0.11$; $SD = 0.40$), $t(17) = 2.46$; $p = .025$. There was also a significant Emotion x Muscle interaction ($F(1,17) = 2.52$; $p = .03$, $\eta_p 2 = .25$). Greater EMG activity was found over the ZM ($M = 0.55$; $SD = 0.37$) compared to the CS ($M = 0.26$; $SD = 0.30$), in response to caresses, $t(17) = 2.34$; $p = .03$ (Figure 1, left panel). Conversely, no difference between ZM ($M = - 0.03$; $SD = 0.54$) and CS ($M = 0.12$; $SD = 0.59$) was found when infants observed scratches, $t(17) = 1.06$; $p = .31$ (Figure 1, right panel).

Further, t-tests on raw data comparing post-stimulus activity (0-2000 ms) to the baseline (500 ms pre-stimulus) revealed that the ZM was significantly activated ($M = 0.010$ μV; $SD = 0.007$) compared to the baseline ($M = 0.009$ μV; $SD = 0.007$) during the observation of caresses, $t(17) = 3.41$; $p = .003$. No other significant muscle activation compared to baseline activity was found (All $ps > .15$). In sum, our results showed that 11-month-old infants responded with selective and matching facial reactions to positive affective interpersonal touch.

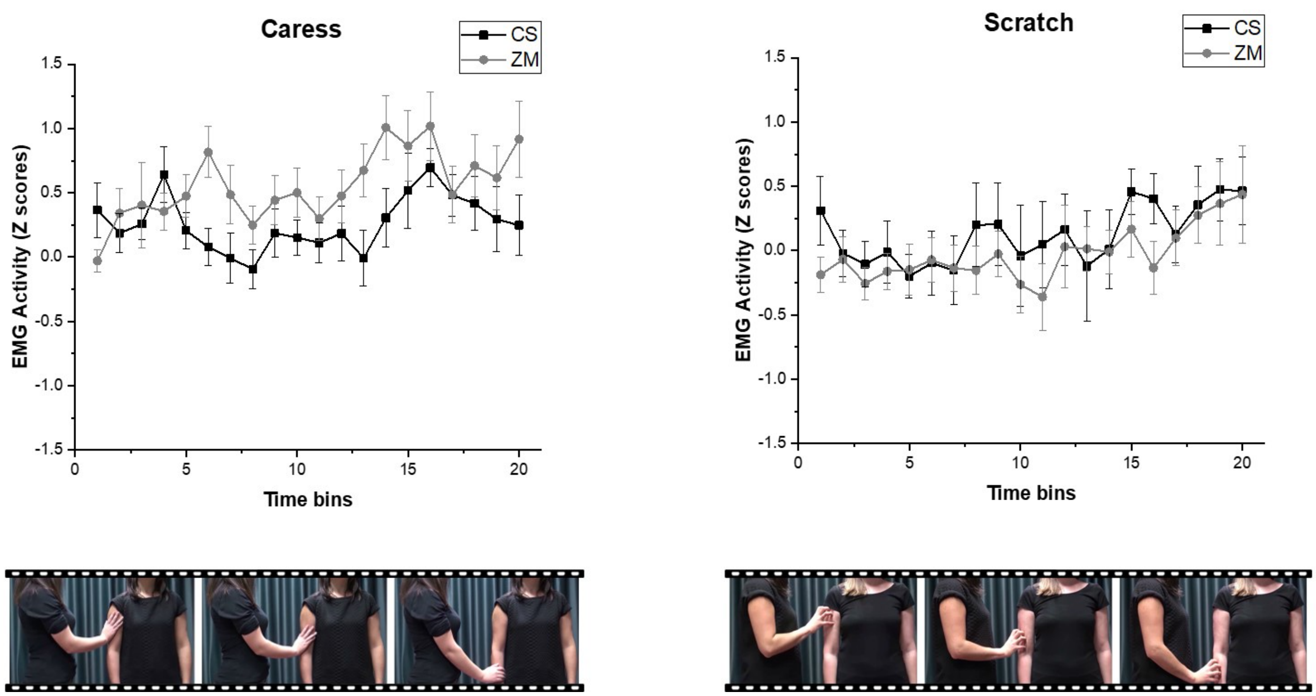

Figure 1. Means of EMG z-transformed activity of the zygomaticus major (ZM) and corrugator supercilii (CS) muscle in the caress and scratch conditions. Below each graph three example frames showing the unfolding of the caress and the scratch are shown.

A Bayesian mixed factor ANOVA with Emotion (Caress, Scratch) and Muscle (ZM, CS) as within-subject factors was runto explore the strength of the muscle x condition interaction. This new analysis determined that the data were best represented by a model that included condition and muscle as main factors and the condition x muscle interaction. The BF10 in favor of indicating the interaction effect (on top of the two main effects) equaled 13.48, strong evidence in favor of this model when compared to the null model. Moreover, information on specific effects of interest was obtained by looking at “BFinclusion” which is the change from prior to posterior odds for a factor averaged across the models that contain that specific factor. Thus, looking at the inclusion BF for each specific effect, there was clear evidence in the data for including Condition (BFincl= 24.23) and evidence for including Condition x Muscle (BF incl 1.56) as predictors in the model.

A difference score was computed by subtracting the EMG z-transformed activity elicited over the incongruent muscle from the congruent muscle. Thus, in the Caress condition, the CS was subtracted from the ZM, while, in the Scratch condition, the ZM activity was subtracted from the CS activity. We then investigated a potential linear relationship between the difference score and the STQ questionnaire administered to the mothers. A linear regression model was conducted separately in the Caress and Scratch conditions. In the Caress condition, no significant association was found between the ZM-CS difference score and the STQ (p = .83). Differently, in the Scratch condition, the infant STQ was a significant predictor of the CS-ZM difference score (Beta = 0.06, p = .004). Specifically, as the avoidance towards social touch increased, the CS-ZM differential activity increased as well (the overall model fit was R2 = 0.42) (Figure 2).

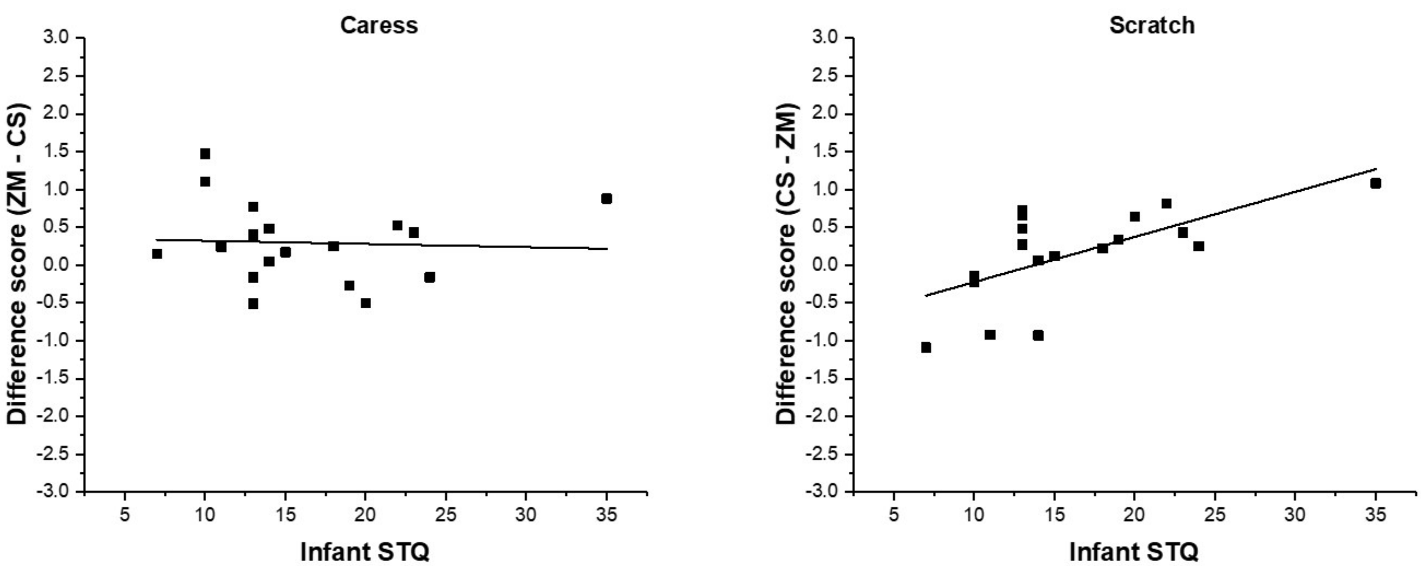

Figure 2. Scatterplot showing the correlation between the difference score in the caress (ZM-CS) and scratch (CS-ZM) condition and infants' attitude toward touch assessed through the STQ questionnaire.

Discussion

The goal of this study was to investigate if 11-month-old infants can extract the emotional content embedded in visual scenes depicting an interpersonal touch. Specifically, we measured the infant's facial EMG activity during the observation of positive (caress) and negative (scratch) interpersonal exchanges. The results show a greater activity in the ZM muscle with no activation of the CS when observing positive interpersonal tactile interactions, compared to no muscle activation in reaction to the negative tactile interactions. Hence, infants manifested sensitivity for the emotional content expressed through positive tactile interaction, displaying congruent facial responses while viewing the positive caress.

Positive tactile interactions are nonverbal signals that show affection and reassurance, for instance, between parent and infant (Field, 2010; Cascio, 2010). Affective touch is something that infants experience very early in life: mothers during pregnancy tend to caress and touch their abdomen and fetuses in the 3rd trimester respond to this maternal touch by increasing movement of their arm, head, and mouth (Marx & Nagy, 2015; Marx & Nagy, 2017). The physiology of affective touch has recently been better understood, revealing the involvement of unmyelinated c-tactile afferents (Löken, Wessberg, Morrison, McGlone, & Olausson, 2009). Several studies have further explored and shown that infants within their first year of life are able to distinguish affective from non-affective touch, as revealed by the frequency of their heart rate (Della Longa, Dragovic, & Farroni, 2021; Fairhurst, Löken, & Grossman, 2014) and EEG responses (Jönsson et al., 2018; Miguel, Lisboa, Gonçalves, & Sampaio, 2019). The robustness of touch in the ability to regulate infants' behavior was previously observed also by Feldman, Singer, & Zagoory (2010), who demonstrated that maternal touch could diminish infants' stress response recorded during a still face paradigm (Feldman et al., 2010). Many of the studies that are investigating touch tend to rely on infants' first-person experience of touching gestures (Fairhurst et al., 2014), this study adds to the topic by looking at touch from a third-party perspective. This study aims to highlight infants' ability to attune to others' affective interpersonal interactions. Our results indicate that positive emotional interpersonal touching content elicits a positive facial response in the infant (i.e., increased modulation of the ZM), revealing that infants are sensitive to affective interpersonal touch interaction.

Infants did not modulate their muscle activity in reaction to the scratches performed by the actress. This might indicate that infants didn't identify the negative significance of the scratches. Future studies could further explore infants' sensitivity to non-affective touch through presenting infants with different kinds of non- affective touch interactions in order to better understand and interpret the origins of the non-significant result we obtained. Furthermore, this study has some limitations. Being a first looking into infants' ability to extract emotional context from an interpersonal interaction, there should be a replication to solidify the findings. Secondly, the attrition rate is considerably high (47% of sample), although having a high attrition rate is typical for studies that use electrodes to measure infants' EMG responses (Isomura &Nakano, 2016). Thirdly, while we showed videos, it could be a possibility that if the stimuli were performed live, we could have a stronger response in the non-affective scratch condition, highlighting a significant modulation of infants' EMG response. Additionally, it's possible that older infants, who have more experience and exposure to touch, might be able to extract the emotional context from the non-affective touch condition.

Generally, infants are exposed to a plethora of affective touches, hugs, kisses, caresses, and are only rarely exposed to non-affective touches, such as scratches. When considering individual differences, we found that differential activation between CS and ZM to scratches may relate with the infant's score in the STQ. Specifically, greater avoidance toward touch in the STQ was associated with great activity of the CS compared to the ZM, suggesting infants that avoid touch in their day-to-day life were more sensitive to the observation of scratches. These results are in line with another study which indicated that individual differences in temperament could modulate infants' attention to negative stimuli (de Haan et al., 2004). Emotions are expressed in numerous different ways, but touch is an essential modality that we use to communicate with one another. This study, for the first time, has shown that infants can extract emotional information conveyed during affective, interpersonal interaction (caresses), and additionally have the ability to identify the emotional valence of the interaction.

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Chapter 3.

Attention to emotional faces is modulated by experiences of maternal touch[1]

The sense of touch conveys important aspects of communication during our entire life, but particularly in early development (Field, 2014; Field, 2010). Receiving affiliative touch (such as a hand squeeze or stroke on the arm) attenuates adults' negative appraisals to negative stimuli, suggesting that touch can modulate the processing of emotional expressions (Wingenbach, Ribeiro, Nakao, Gruber, & Boggio, 2021). Furthermore, married women holding the hand of their significant other showed a reduced neural reaction to a threat (Coan, Schaefer, & Davidson, 2006), giving evidence that touch can provide a feeling of calm and security. This calming effect is also observed in childhood, when parents place a hand on their child's shoulder, children pay less attention to threatening stimuli (Brummelman, Terburg, Smit, & Bögels, 2019). Furthermore, gentle maternal touches increase infants' attentional resources and learning of facial information (Della Longa, Gliga, & Farroni 2019). It is known that affective touch involves the C-tactile afferent nerves that are sensitive to light touches or strokes (McGlone, Wessberg, & Olausson, 2014; Cascio, Moor, & McGlone, 2019). The optimal activation for these nerve fibers is at a slow caress with a velocity of 1-10 cm/s, and their firing is linked with reports of pleasantness, suggesting that the C-tactile nerves are linked to positive stances (Della Longa, Carnevali, Patron, Dragovic, & Farroni, 2021; Löken, Wessberg, McGlone, & Olausson, 2009). Hence, evidence

[1]Data, results, and parts of the text reported in this chapter are published in a paper by Addabbo, Licht, & Turati (2021) 'Past and present experiences with maternal touch affect infant's attention toward emotional faces' (Addabbo, M., Licht, V., & Turati, C. (2021). Past and present experiences with maternal touch affect infants' attention toward emotional faces. *Infant Behavior and Development*, *63*, 101558.)

converges to suggest that touch plays a crucial role within interpersonal communication and can affect how we process the emotional world around us.

Early in life, infants demonstrate a sensitivity to emotional facial expressions, having the ability to discriminate between different emotions (Addabbo, Longhi, Marchis, Tagliabue, & Turati, 2018). Even in the first few days of life, newborns prefer happy facial expressions over angry expressions (Farroni, Menon, Rigato, & Johnson, 2007). At 7 months, infants tend to look longer at fearful faces over happy or neutral ones, and they are less likely to disengage from fearful faces to look at other stimuli (Leppänen & Nelson, 2012). Also, event-related potentials (ERPs) differentiate infants' perception of emotional faces. For instance, at 5-, 7-, and 12-months of age, greater responses to angry faces than happy or fearful faces have been reported in the Negative central (NC), which is an attentional ERP component (Xie, McCormic, Westerlund, Bowman, & Nelson, 2019). Additionally, 3- 4 months old infants showed increased levels of arousal, measured through skin conductance response (SCR), when responding to angry over happy facial expressions (Nava, Romano, Grassi, & Turati, 2016).

Angry expressions are salient and arousing stimuli for infants, but when compared to happy expressions during a preferential looking task, the angry face elicits a greater avoidance visual response pattern (Grossman et al., 2007). This looking pattern is measured in infancy as reduced dwell times with fewer fixations toward angry faces (Hunnius, de Wit, Vrins, & von Hofsten, 2011). Infants are still in the rudimentary stages of emotional regulation, as they tend to depend on their parents to help regulate their internal states. The maternal touch could have a very important role, helping infants to regulate their arousal response toward threatening faces and possibly reducing avoidance and promoting visual exploration of these expressions.

The aim of this study was to explore the role that maternal touch has on 7-month-olds sensitivities toward emotional facial expressions. This was evaluated in two steps. First, by manipulating the kind of touch the infant received during the experiment, affective vs. non-affective touch. Both types of touch were provided by the mother to the infant while they watch happy and angry facial expressions. This allowed us to evaluate the short-term effect of maternal touch on their infant's reaction to the emotional video. Secondly, we examined whether past experience with maternal affective touch could impact the visual exploration of emotional faces in infants. To measure the frequency of maternal affective touch provided by the mother to the infant, we used the Parent-Infant Caregiving Touch Scale (PICTS; Koukounari, Pickles, Hill, & Sharp, 2015). Using a two-trial preferential looking setup, we measured 7-month-olds' looking time to dynamic happy and angry facial expressions within two different conditions. In the first condition, mothers gently stroked their infant's arm (affective touch), while in the second condition mothers gave their infant a gentle squeeze (non-affective touch).

We predicted that the mother's affective touch would provide a sense of calm and safety that would encourage infants to explore the angry facial expressions. The effect could be reached by either a short term (maternal touch that happens during the study) or long term (the frequency of affective touch between mother and infant in the week before the study) period. Additionally, another possibility is that both maternal touches happening during the testing and past experiences with maternal touch could modulate the effect of emotional processing. If this were the case, touch happening at the time of the testing might affect infants' visual exploration of angry expression, but only when infants had a higher frequency of affective touch during their day-to-day contact with their mothers.

Methods

Participants

The final sample included 40 healthy full-term 7-month-olds (27 females, mean age = 210 days, range = 196–232 days). An additional 13 infants were also tested but were not included in the final sample due to fussiness (N = 10) and the mother not following instructions adequately (N = 3). Sample size was based on previous eye tracking studies (N=48 in Della Longa et al., 2019; N=31 in Hunnius et al., 2011). The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki (BMJ 1991; 302: 1194) and approved by the Ethical Committee of the University of Milano-Bicocca. Parents gave their written informed consent before the testing session began.

Stimuli

Stimuli were dynamic videos of two Caucasian women performing happy and angry emotional facial expressions with a directed gaze. Stimuli were selected from the Amsterdam Dynamic Facial Expression Set (ADFES; Van Der Schalk, Hawk, Fischer, & Doosje, 2011), and infants were randomly assigned to one of the two female models (F01, F03 of the ADFES). The two videos displaying happy and angry facial expressions were shown simultaneously and bilaterally on the screen at a distance of 20 cm. Each model initially displayed a neutral expression that, after 1000 ms, unfolded to the target emotion expression, which was held for 2000 ms. Hence, the total duration of the videos was 3000 ms. At a distance of 60 cm from the screen, both face A and B were 13◦ wide and 18◦ high. Luminance was kept constant between emotions.

Procedure

Infants sat on the mothers' lap in front of the stimulus presentation monitor (24" screen size, 1920 × 1080 pixel resolution, 60 Hz), at a distance of about 60 cm. Infants' gaze direction was recorded by a video camera, and the stimulus presentation was designed with E-Prime 3 (Psychology Software Tools). As soon as the infant looked at a flickering white circle displayed in the center of the screen, two experimental trials were presented. In each trial, the two emotional expressions were presented 10 times in a loop, for a total duration of 30,000 ms.

The left/right position of the stimuli was counterbalanced across participants and across trials. At the end of each trial, the central circle re-appeared to attract the infants' gaze to the center of the screen. As soon as the infant looked at a flickering white circle displayed in the center of the screen, two experimental trials were presented. In each trial, the two dynamic emotional expressions were presented 10 times in a loop, for a total duration of 30,000 ms. The left/right position of the stimuli was counterbalanced across participants and across trials. At the end of each trial, the central circle re-appeared to attract the infants' gaze to the center of the screen. At the beginning of each presentation of the emotional facial expressions, a sound was presented through the headphones worn by the mother, which lasted for 1000 ms. The sound signaled the mothers to start delivering the touch to their infant. When the sound ended, the mother stopped the tactile stimulation. Thus, tactile stimulations lasted for the duration of the sound, which was 1000 ms. Overall, infants received 10 tactile stimulations per trial. Infants were assigned to one of two experimental conditions in which the mother, during the stimulus presentation i) gently stroked the infant's arm from the shoulder to the elbow (Affective Touch); ii) gradually squeezed the infant's arm between the shoulder and the elbow (Non-affective Touch). The maternal stroke on the infants' arm was chosen as an affective stimulation, being a very familiar expression of affect in the mother-infant dyad. While the fingertip squeeze on the infants' arm was chosen as a non-affective stimulation, being a touch that is easy to perform by the mothers and that didn't distract infants' attention. Half of the infants (N = 20) received a tactile stimulation on the right arm and the other half (N = 20) on the left arm to avoid spatial attentional biases driven by touch. The mothers were trained on how to stroke/squeeze their infant's arm while keeping the infant on their lap. Mothers had their eyes closed during the testing session and were asked to stroke or squeeze their infant arm (skin-to-skin contact) synchronously to when they heard a piano sound through the headphones, starting at the beginning of each video. The velocity of the stroke/squeeze was kept constant by asking mothers to follow the rhythm of the sound. The speed of the touch(10cm/s) was within the range considered optimal for CT fiber activation (1− 10cm/s) (Löken, Wessberg, McGlone, &Olausson, 2009). The mothers were asked not to interact verbally with the infant and to deliver tactile stimulations other than the experimental ones. Tactile stimulations were validated by 13 adults (8 females, mean age = 30.8 years, SD = 4.2), who, after receiving on their arm the caress and the squeeze with a counterbalanced order across participants, were asked to judge on a 7 point Likert-scale: 1) whether the perceived touch was affective or not affective, from 'not affective at all' (−3) to 'very affective' (+3); 2) the valence of the touch, from 'very negative' (−3) to 'very positive' (+3) ;4) the pleasantness of the touch, from 'very unpleasant' (− 3) to 'very pleasant' (+3). Paired sample t-tests revealed that only the caress was rated as affective (Mean, M = 1.9, Standard Deviation, SD = 0.7) while the squeeze was rated as non-affective (M = − 0.7, SD = 1.9); t(12) = 4.463, p = .001). The caress was also rated as more positive (M = 2.2, SD = 0.8) than the squeeze

(M = − 0.5, SD = 1.5, t(12) = 5.740, p < .000), and more pleasant (M = 2, SD = 0.8) than the squeeze (M = − 0,1, SD = 1.1, t(12) = 5.671, p < .000).

Total looking times were coded offline by an experimenter blind to the stimuli shown. To assess intercoder-agreement, a second experimenter, also blind to the stimuli shown, coded offline 50 % of the infants' looking behavior. The inter-coder agreement (Pearson correlation) on 50 % of the sample was .92 for total fixation. The Intra-Class Correlation (ICC) coefficient was .95.

Questionnaire

To assess the frequency of maternal affective touch during mother-infant interactions, we administered to the mothers, after the experimental session, the Parent-Infant Caregiving Touch Scale (PICTS) (Koukounari et al., 2015). This questionnaire reflects commonly observed parental behaviors in early parent-infant interactions coded on a 5-point Likert scale (1=Never; 2=Rarely; 3=Sometimes; 4=Often; 5 = A Lot). Twelve items assessed how often the mother stroked in the past week her infant's back, head, tummy, arms, and legs. The remaining items reflected various other forms of touch or communication, specifically how often they were picked up, cuddled, rocked, kissed, and held. The total score ranged from 0 (lowest frequency of mother-infant touch) to 60 (highest frequency of mother-infant touch).

Results

A median split was obtained from PICTS score to create categorical groups of lower and higher frequency of touch in the mother-infant dyad (low: M = 46.6, SD = 4.1; high: M = 52.1, SD = 12.8). A repeated-measures Analysis of Variance (rmANOVAs) on total fixation times with

Emotion (Happy vs. Angry) as within-subjects factors and Touch (Affective Touch vs. Non-Affective Touch) and Frequency of touch (Low vs. High) as between-subjects factors revealed a significant Emotion ($F (1,36) = 21.37$, $p = .0005$, $\eta 2p = .372$) main effect. Infants looked longer towards the Happy facial expression (M = 26.7 s; SD = 6.4) compared to the Angry face (M = 20.1 s; SD = 7.1). Further, there was a significant Emotion x Touch x Frequency of touch interaction, $F(1,36) = 13.946$, $p = .001$, $\eta 2p = .279$. All the other main effects and interactions didn't reach significance (All ps > .46). Follow-up t-tests (Bonferroni-Holm corrected) revealed that, in the affective touch condition, infants with low mother-infant frequency of touch looked significantly longer to the happy expressions (M = 29.9 s; SD = 6.8) compared to the angry one (M = 16.6 s; SD = 6.4), $t(10) = 4.73$, $p = .004$. Infants with a high frequency of mother-infant touch didn't show differences in looking times between happy (M = 24.4 s; SD = 5.2) compared to the angry expression (M = 23.6 s; SD = 7.9), $t(8) = 0.29$, $p = .78$ (Fig. 1b). In the non-affective touch condition, infants with low mother- infant frequency of touch showed no differences in looking times between happy (M = 24.44 s; SD = 5.6) compared to the angry expressions (M = 22.72 s; SD = 6.2), $t(10) = 0.69$, $p = .50$. Conversely, infants with high mother-infant frequency of touch looked significantly longer to the happy expressions (M = 27.5 s; SD = 6.9) compared to the angry one (M = 17.4 s; SD = 5.5), $t(8) = 3.18$, $p = .039$ (Fig. 1b).

Overall, infants that were more biased towards happy expressions and that showed more avoidance of the angry face were those who received affective touch and had lower PICTS scores and, additionally, those who received non-affective touch and had higher PICTS scores. A difference score between total looking times towards happy and angry facial expressions was computed in order to investigate a potential linear relationship between emotional biases and the Questionnaires administered to the mothers in the two experimental conditions (Affective touch, Non-affective touch). A linear regression model was conducted separately in the Affective and Non- affective touch condition, testing whether the PICTS scores predicted the happy-angry difference score. In the Affective touch condition, the PICTS was the significant predictor of happy-angry difference score (Beta = − 0.64, p = .003). Specifically, as the PICTS scores increased, the attentional bias towards happy faces decreased (The overall model fit was R2 = 0.40). The PICTS was also a significant predictor of happy-angry difference score in the non-Affective touch condition (*Beta* = 0.54, p = .014). Conversely, in the non-affective Touch condition, as PICTS scores increased, the attentional bias towards happy faces increased as well (the overall model fit was R2 = 0.29) (Fig. 1c). Regressions show that the frequency of affectionate maternal touch represents a strong predictor of the effects that affective and non-affective maternal touch has on infants' differential looking times towards happy and angry expressions.

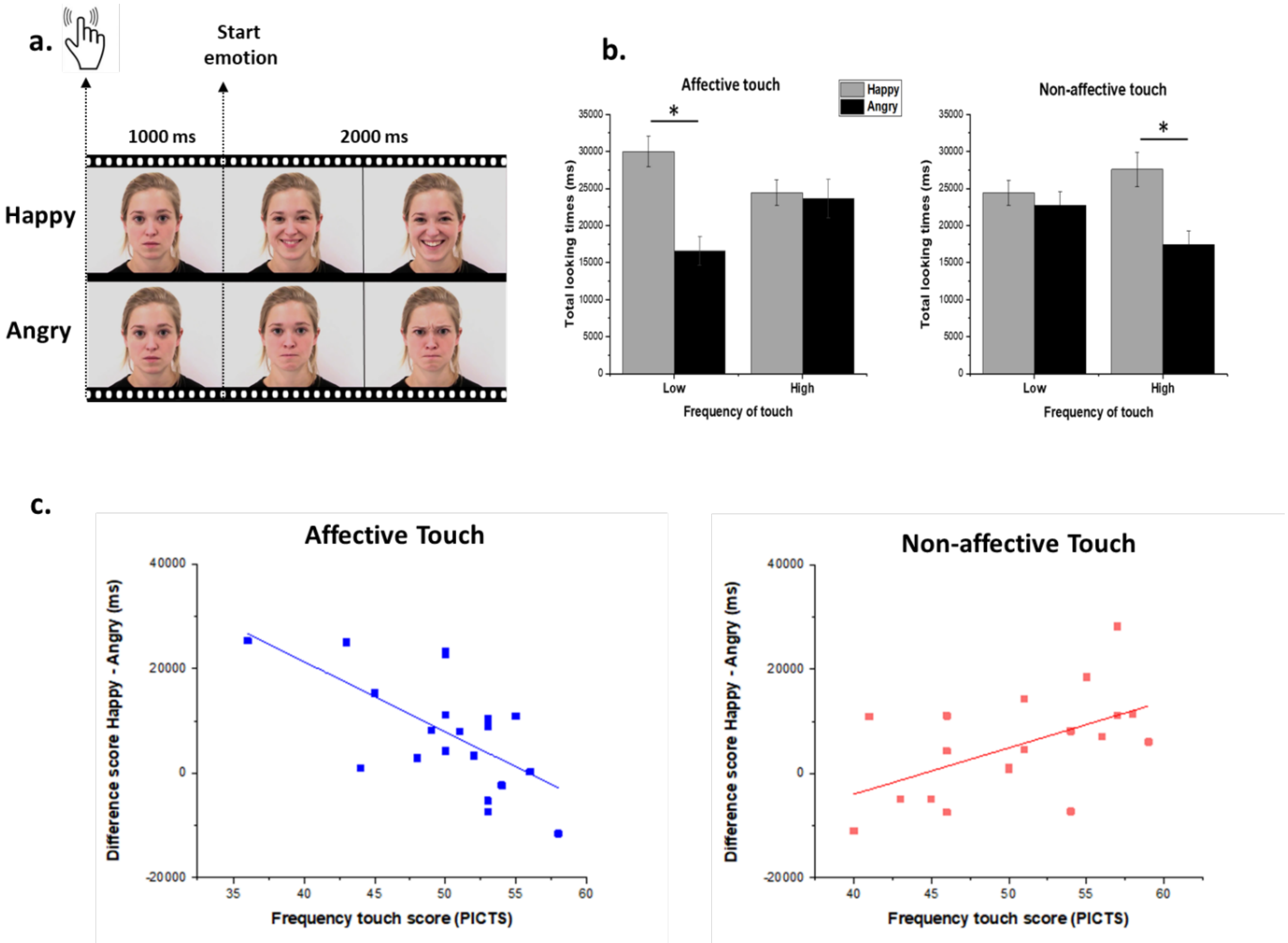

Figure 1. Stimuli and Results. a) Three frames taken from the Happy and Angry videos. b) Total looking times toward Happy and Angry stimuli in the group of infants with Low and High frequency of maternal touch, in the affective and non-affective touch experimental conditions. C) Scatterplots showing the correlations between the happy – angry difference score and the frequency of maternal touch assessed through the PICTS questionnaire in the affective (Left panel) and non-affective (right panel) touch condition.

Discussion

This study aimed to explore how maternal touch could modulate infants' visual exploration of emotional facial expressions. Overall, the results demonstrated that the effect of touch provided by the mother during the presentation of emotional faces impacts the visual attention of an infant, but the exerted effect is modulated by the previous infant's experience with maternal affective touch. We found that infants in the affective touch condition and with higher frequency of maternal touch showed less avoidance toward angry faces. Infants in the non-affective touch condition with higher frequency of maternal touch had a greater aversive response toward the angry expression. So, the accumulation of mother-infant daily interaction of maternal affective touch represents a predictor of how, during a specific situation, touch can affect an infant's visual explorative behavior. Previous studies converge to suggest that, in non- affective touch conditions, infants manifest a visual avoidance towards angry faces (Grossmann et al., 2007). Interestingly, our findings expand this evidence, demonstrating that maternal touch can modulate and adjust this avoidance behavior toward angry faces.

The results are in line with our hypothesis, according to which affective touch exerted a calming effect and encourages infants to explore angry facial expressions. Indeed, when given a social touch adult participants also slow down their gaze aversion to subliminal angry facial expressions compared to happy expressions, showing that touch has a calming influence and renders participants less vigilant to angry expressions (Meier, van Honk, Bos, & Terburg, 2020). While in infancy affective touch can be seen to have a calm effect (Fairhurst, Löken, & Grossmann, 2014), additionally previous literature indicated that infants will have a visual avoidance or vigilance behavior when presented with angry faces (Grossmann et al., 2007; Nava et al., 2016). Specifically, angry expressions are more salient and arousing for infants when presented for short periods of time (100-200 ms, Nava, et. al., 2016), but infants exhibited visual avoidant behavior when the angry face was shown for a longer time, as in preferential looking paradigms (90s, Grossmann et al., 2007).

In the current study, infants who typically received higher frequency affective touch from their mother (higher score in the PICTS questionnaire), when in the non-affective touch condition might have felt insecure in their environment, causing them to look longer at happy faces to feel rewarded. While infants who had a lower score in the PICTS questionnaire did not perceive a difference in the non-affective touch condition, unlike in the affective touch condition they might have felt comforted and looked longer at the happy facial expressions. Overall, the results suggest that short term affective touch can modulate visual exploration of emotional stimuli when considered in association with infants' previous experience with maternal touch. These findings shed light on how vital touch can be when infants watch emotional stimuli and how their previous experience with affective maternal touch in combination with their present situation can lead to changes in visual exploration of emotional stimuli.

It is important to be aware that this study does have some limitations. First, since this questionnaire was entirely self-reported from the mothers, this could have caused a bias in the scores. PICTS questionnaire had an overall medium-high range scale, scoring between 36 and 59. Secondly, infants were also all seated on the mother's lap while observing the facial expression, this could have given infants the feeling of a secure environment, from body proximity alone. Future studies should examine infants-mother dyads with lower scores in PICTS, possibly looking at mothers that suffer from depression.

To conclude, this study was the first venture looking at how past and present touch experiences play an important role in the regulation of visual behavior in infants. Our results showed that maternal touch can affect infants' looking times, supporting the exploration of visually threatening stimuli.

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Concluding remarks

Throughout our lives we experience and observe an incredible number of social interactions in various ways. As infants, our initial interactions crucially involve touch, for instance when we are being held by our caregivers. We are constantly observing a vast range of social interactions that populate our environment. The studies presented in this thesis demonstrate that infants at a young age can differentiate social and emotional touching interactions, and that social touch from their mother can alter their attention to emotional stimuli.

First, we demonstrated that, at 5-6 months of age, infants' neural activity can differentiate between prosocial and antisocial observed actions. Interestingly, the results also revealed that prosocial and antisocial situations elicited specific ERP components, as antisocial interactions were assigned more attention, while prosocial interactions involved more cognitive processes.

Secondly, the results revealed that, by 11 months of age, infants' facial responses are modulated by the emotional information conveyed by a positive touching interpersonal interaction (caress from one person to another). In fact, infants responded to the caress interaction with higher activation of their own ZM, but not the CS, muscle.

Finally, we examined whether and how experiences of their mother touch modulated infants' attention toward emotional stimuli. Infants who had a higher frequency of previous experience of touch and who received affective maternal touch while observing the emotional stimuli decreased their avoidance of the angry face. However, those who had a higher frequency of previous touch experience and but did not receive affective touch from their mother, avoided the angry faces more.

Infant research dedicated great efforts to investigate how visual environment might shape the early development of mind, and how infants discriminate, recognize and categorize visual stimuli. Infants' auditory environment has been also largely investigated, as well as its impact on, for instance, the emergence of infants' language competences. These research topics are vital in shedding light on how infants perceive and learn from the world around them. Nonetheless, much less effort till now has been dedicated to how infants perceive social interaction mediated by the sense of touch. . Touch is one of the first forms of social interactions we have in our life and is a critical factor in our social development, especially in forming social bonds. Our findings provide evidence that further shows the importance of touch early in life. Infants are capable to discriminate, recognize, and interpret different social and touching interactions. Therefore, social and touching interactions that populate infants' environment can heavily shape infants' developing minds. This might have important implications on both the educational and clinical practice.

We are born into a society where being social and interacting with one another is important, where social interactions are inevitable and become more and more complex as we grow. The studies reported in the current dissertation add further knowledge about the early development of social cognition, shedding light not only on infants' capacity to perceive and understand their social environment, but also their caregivers' capacity to modulate the infants' attentional processing, buffering the impact of potentially threatening stimuli.