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EVERY MOVE YOU MAKE: MOVEMENT CONVEYS SOCIAL INFORMATION DURING INFANCY AND CHILDHOOD.

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"Anything that happens, happens.

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Anything that, in happening, causes something else to happen,
causes something else to happen.

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Anything that, in happening, causes itself to happen again,
happens again.

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It doesn't necessarily do it in chronological order, though".

Douglas Adams

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Abstract

Movement pervades our daily life and affects our social world. From the very beginning of human life, it provides information through active experience of the body and the environment. This thesis will analyze the contribution of movement in the socio-emotional development, from the most fundamental features (i.e., the kinematics) to more complex ones, embedded in a multi-personal context.

First, the focus will be on how the kinematics of two emotions (happiness and fear) can be identified by 7- and 10-year-old children, to explore whether dynamic features of body language are differently involved in the recognition of emotions compared to static ones (Chapter 1). Secondly, facial emotional displays will be considered. Specifically, we will investigate whether the observation of faces expressing dynamically happiness or anger is able to activate the sensorimotor cortex (reflected by a differential modulation of mu-rhythm desynchronization) at 7-months of life (Chapter 2). Movement will be then examined in social exchanges. The aim of the presented study will be to investigate whether an action-sound association is perceived as key towards the construction of interactive scripts by 10-month-old infants (Chapter 3). Planning movement and actions towards novel objects is also influenced by social messages provided by others. We will then finally investigate how the two actions of holding an object or pushing it away are processed at a neural level by 10-month-olds, and whether providing an emotional context in which those actions took place alters their perception (Chapter 4).

Overall, our findings show that, during development, observing movement from its most basic forms to more complex social exchanges, can unveil social messages about others' emotions and actions in everyday life.

Abstract (Italian version)

Il movimento è fondamentale nelle nostre vite di tutti i giorni, e ha grande influenza nella percezione del mondo sociale. Fin dai primi giorni di vita, è fonte di informazioni che emergono attraverso l’esperienza sia del proprio corpo che dell’ambiente che ci circonda. Questa tesi analizzerà il contributo del movimento nello sviluppo socio-emotivo, a partire da caratteristiche percettive di base (la cinematica) sino a situazioni sociali complesse, inserite in un contesto multi-personale.

In primo luogo, verrà analizzata la capacità di bambini di 7 e 10 anni di identificare due emozioni (felicità e paura) attraverso la cinematica, per esplorare se le caratteristiche dinamiche del linguaggio del corpo siano diversamente coinvolte nel riconoscimento delle emozioni rispetto a quelle statiche (Capitolo 1). In secondo luogo, saranno prese in considerazione le espressioni emotive del volto. In particolare, attraverso l’analisi delle oscillazioni di un particolare ritmo EEG (ritmo mu), indagheremo se, a 7 mesi di vita, l'osservazione di volti che esprimono dinamicamente felicità o rabbia sia in grado di attivare la corteccia sensomotoria (Capitolo 2). Il ruolo del movimento sarà in seguito preso in esame nell’ambito degli scambi sociali. L'obiettivo dello studio presentato sarà quello di indagare se i bambini di 10 mesi siano in grado di cogliere l'associazione tra l’azione di una persona e il suono di risposta del suo interlocutore (capitolo 3). Infine, poiché è noto che la pianificazione delle azioni verso nuovi oggetti è influenzata dai messaggi sociali altrui, studieremo come le azioni di avvicinare a sé un oggetto o di spingerlo lontano siano elaborate a livello neurale dai bambini di 10 mesi, e se il contesto emotivo in cui queste azioni hanno avuto luogo alteri la loro percezione (Capitolo 4).

Nel complesso, i nostri risultati mostrano che, durante lo sviluppo, l'osservazione del movimento dalle sue forme più semplici agli scambi sociali più complessi, può rivelare messaggi sociali sulle emozioni e le azioni altrui nella vita di tutti i giorni.

General introduction. Movement, embodied cognition and the social world.

Movement is a concept that implies multiple features. When we think about it, the aspect that comes to our mind first is probably our ability to walk, run, jump, dance, or our capacity to go from a point A to a point B. In doing so, we are implicitly thinking of the whole body. But, if we consider it more carefully, we will probably realize that movement is informative at many more levels. When we are talking to someone, if he or she rises an eyebrow we will be immediately concerned about whether what we are saying is clear. When we are walking in a calm street, we detect every type of sudden movement, produced by other people, but also objects and events in the surrounding environment (for instance, a car when we need to cross the road). We are also very well trained to understand if our friends or family members are happy or sad, just by looking at subtle facial expressions that for others would be almost impossible to decode. Or again, when we play charades, we decipher all kinds of messages conveyed by other people’s bodies, without the need of linguistic information. Movement is indeed a complex feature, difficult to be narrowed down to few components.

Traditionally, movement as a human characteristic was described primarily in the form of motor control (Rosenbaum, 2002). The idea behind this was that a central control system, specifically the central nervous system, would be in charge of both the creation of motor programs and their execution (Schmidt, Lee, Winstein, Wulf & Zelaznik, 2018). But this top-down view of the body as subject to a central motor control system is in contrast with the evidence provided by everyday life that the body and the environment influence motor behavior as well. Indeed, the embodied cognition theory states that cognition is strictly depending on the agent’s physical body that in turn not only serves it but, rather, is an integral part of it (Wilson & Foglia, 2011). It would do so in two ways: as a limitation, that constrains what can be perceived, and as a tool to collect information that influence the development of cortical structures and higher-level cognitive functions (Kiverstein & Miller, 2015). For instance, Varga & Heck (2017) gathered evidence on how control over respiratory processes impact even cognitive processes such as motor control, sensation, and emotion. Respiration also influences neural rhythms (in particular, gamma oscillations) which in turn influence widely the same cognitive processes, together with many others such as attention, memory and language processing and cortical activity in general (Varga & Heck, 2017). Brain, bodies and environment are indeed in continuous dynamic interaction (Hoffmann & Pfeifer, 2012).

Although the embodied cognition is more intuitively applicable when we think of walking, reaching towards an object or making facial expressions, it also extends to perception at all levels, such as visual perception. Observing the environment is not a passive state, on the opposite, it is linked to acting in a flexible and adaptive way (Adolph & Berger, 2007). Perception and action are indeed intertwined, as exemplified by the tendency to turn our eyes where our attention is directed, fundamental for exploring the environment, acting in a goal-directed manner and learning how to interact with others (von Hofsten, 2013). A growing body of research is suggesting this strong association between perception and action and highlights the involvement of a wide network of brain regions that are activated during both the observation and execution of movement (Rizzolatti & Luppino, 2001; Ninomiya, Noritake, Kobayashi & Isoda, 2020). Therefore, action is not a limiting factor in our cognitive functioning but can be considered an integral part of cognition. For example, the mere intention to act can change the way distance is perceived: distance appears as bigger when the perceiver intends to throw, and smaller when he/she intends to use a tool (Witt, Proffitt & Epstein, 2005; 2010). Furthermore, even when emotional stimuli are presented so briefly that perceptual awareness is not reached, they can trigger emotion-related physiological or behavioral reactions (Tamietto and de Gelder, 2010).

Movement is key from the very beginning of human life: fetuses, as early as 16 weeks of gestational age, are able to perform not only general movements, but also more specific and coordinated movements, such as directing the hand towards the mouth (Sparling & Chescheir, 1999; Addabbo et al., 2015). Nonetheless, for a prolonged period of time motor abilities are not developed enough to allow an independent exploration of those elements of the environment that require the ability to roam autonomously. While at birth infants are almost entirely subject to gravity, by the end of their first year, they master a great number of locomotor movements (e.g., rolling, crawling, supported stepping, and independent walking, Figure 1) (Adoplh, 2008).

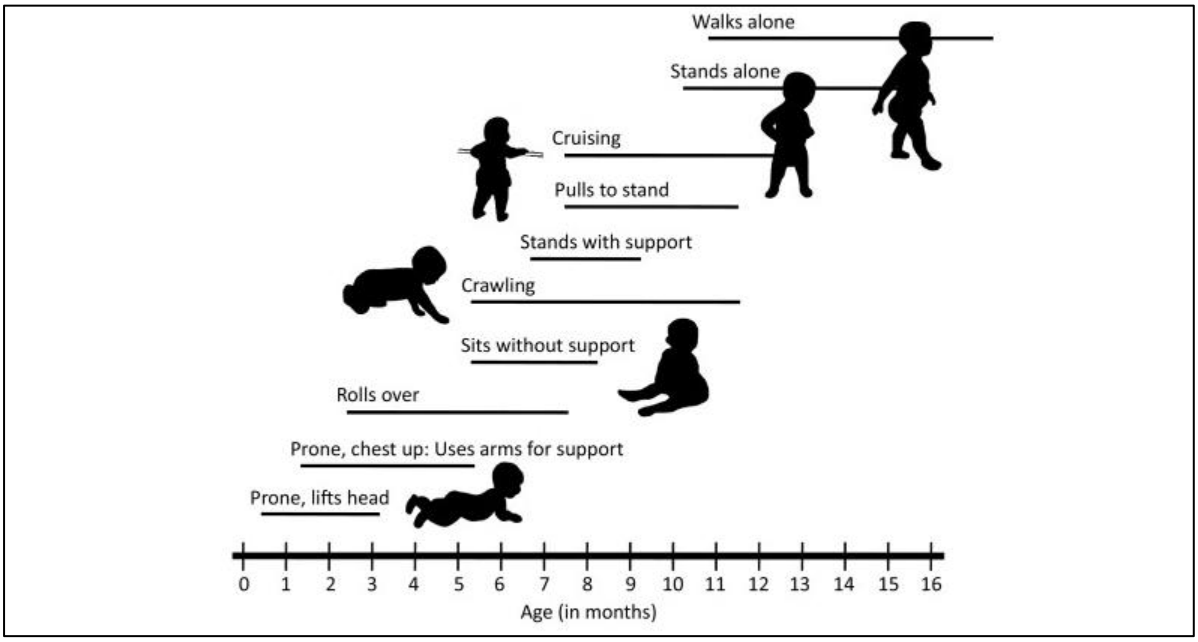

Figure 1. Sensory–motor skills and postures changes over the first 16 months (Byrge, Sporns & Smith, 2014).

These dramatic changes in infant’s motor skills imply that before the first year of life infants have limited autonomy in moving around. As infants, and even children, acquire more control on their motor abilities and experience self and others moving and interacting, they develop other functions, like voluntary control of attention (Yu & Smith, 2016), action and emotion understanding (Addabbo & Turati, 2020). When the possibility of moving around independently is absent, infants rely greatly on observation to acquire meaningful information about their physical and social environment. A growing body of literature is indeed showing how the mere observation of actions is actively represented in the somatosensory areas of infants' brain as much as performing an action is. Through bodily experience and observation, we develop the ability of understanding others' actions (Gallese, Keysers & Rizzolatti, 2004). One of the most used indexes of such mechanisms is the mu-rhythm, i.e., alpha frequency band oscillations (between 8 and 13 Hz in adults) in electrodes recorded over the sensorimotor areas (Pineda, Allison & Vankov, 2000; Muthukumaraswamy & Johnson, 2004). When subjects move, imagine, or observe movements, these neurons fire asynchronously, resulting in attenuated mu amplitudes (mu-rhythm suppression) (Babiloni et al., 2002; Pineda, 2005). Children, and even infants, already show such sensorimotor areas activation reflected by alpha suppression in response to actions' observation and execution (Marshall, Bar-Haim & Fox, 2002; Marshall & Meltzoff, 2011). For instance, in a study by Quadrelli and colleagues (2019), 9-month-olds watched point-light displays depicting a hand performing a grasping action in the presence or absence of a ball while their brain activity was recorded. Stronger attenuation of alpha activity was observed during the reaching phase, regardless of the presence of a graspable object, while during an earlier time window, defined as an "anticipatory phase", the alpha suppression was observed only in trials in which the to-be-grasped object was present (Quadrelli, Roberti, Turati & Craighero, 2019). This finding confirms that infants are actively creating predictions of motor outcomes (Southgate, Johnson, Osborne & Cisbra, 2009). Indeed, although first person motor experience is relevant to foster the understanding of others' actions (Rotem-Kohavi et al., 2014), the multi-directional links between brains, bodies and environmental stimulations make the opposite direction of interpretation (i.e., understanding and observing others acting enhances one's own motor skills) equally true. Pilot work on children with cerebral palsy that underwent a 6-week Action Observation Treatment, showed that at the end of the treatment participants revealed an increased mu-rhythm desynchronization at scalp locations corresponding to the hand representation areas. This result was also associated to functional improvement of the upper limbs movements (Quadrelli et al., 2019). The action observation alone seems to be a promising rehabilitative strategy to increase such skills in a clinical sample with impaired upper limbs motor skills.

The first stages of development are a particularly salient example of the interplay between perception and action. Motor development is a complex phenomenon and can therefore indirectly provide information about other cognitive domains, such as perception (Adolph & Berger, 2007), action planning (Von Hofsten, 2004), and cognitive control (van der Fels et al., 2015; Wu, Liang, Lu & Wang, 2017). This means for instance that when we are talking about perception, we are not only referring to something that happens in the environment and that the infant, or the child detects. Rather, we imply that each one of us, starting from the earliest stages of development, actively select the relevant information. In the words of the robotics sciences, we “self-structure” perceptual information (Pfeifer, Lungarella, Sporns, & Kuniyoshi, 2007).

The active learning described so far suggests that, even before infants can implement complex actions or interactions, they are encoding information and creating representations that allow them to learn how to act and how to behave in a social environment. Infants develop in a world filled with other people and learning how to read social messages and efficiently interact with others, whether they are members of the family or strangers, is fundamental for their well-being and optimal functioning throughout life (Csibra & Gergely, 2006; Grossmann & Johnson, 2007). These social messages are not only cues towards shared actions, but also emotional signals. The latter ones have a role in regulating both behavioral (Walle, Reschke, Camras & Campos, 2017) and emotional states (Housman, 2017). Therefore, developing an understanding of others can be considered one of the most fundamental tasks infants face in learning about the world.

Many studies show how movement is particularly relevant in emotions’ perception (Dael, Mortillaro & Scherer, 2012) and social interactions’ interpretation (Froese & Fuchs, 2012) in adults. But the developmental trajectory is long, as socio-emotional development starts early in human life. At birth, newborns already have the ability to extract information from faces, as shown by their preference for face-like stimuli (Goren, Sarty & Wu, 1975; Johnson, Dziurawiec, Ellis & Morton, 1991). During their first year of life infants’ ability to process emotions gradually develops. At first, they are able to discriminate between facial expressions of emotions: surprise and happiness at 3 months of age (Young-Browne, Rosenfeld & Horowitz, 1977), anger and happiness at 4 months (LaBarbera, Izard, Vietze, & Parisi, 1976), fear and happiness at 7 months (Kotsoni, de Haan &

Johnson 2001; Ludemann & Nelson, 1988). Only later they are capable of matching emotional faces with an emotional tone of the voice, indicating a comprehension of the communicative functions that emotions hold (Hepach & Westermann, 2013; Grossmann, 2010). This understanding happens between 7 and 10 months of life, when infants develop the ability to categorize facial expressions despite changes in intensity (Ludemann & Nelson, 1988; Bornstein & Arterberry, 2003), across individual identities (Kotsoni, de Haan & Johnson, 2001), and, more importantly, across modalities (Ruba & Repacholi, 2020). The accuracy in emotions' recognition keeps increasing for a long time. For instance, when they are conveyed through body movements, a considerable increase in accuracy can observed after 8 years of age, although improvement continues at a slower rate for all adolescence (Ross et al., 2012).

This thesis aims to explore how infants and children can infer complex socio-emotional messages from observed movement. Rather than following a developmental trajectory and present first the studies run with infants and afterwards those run with children and adults, we chose to follow the increasing degree of complexity of both observed movement and complexity of the social messages that it conveys. Therefore, the **first** study investigated how movement, per se, can contribute to school aged children's comprehension of emotions. Although emotions are usually thought of as somethings that is mainly expressed through faces and voices, body movements are often as meaningful in conveying meaning about an emotional situation (Atkinson et al., 2004). In daily life bodies and faces are presented simultaneously, as a complex and complete source of information. This makes it difficult to narrow down to what are the constituent elements of an emotional message, for instance whether the kinematics is enough or pictorial information is required. The study presented in **Chapter 1**, ***The kinematics of emotions: 7- and 10-year-old children detect emotional information based on kinematic information***, aims to provide explorative evidence for the idea that the kinematics alone, portrayed through a single point moving, can successfully convey information about emotions. Moreover, the use of different emotions (i.e., happiness and fear) will unveil possible differences in the way various emotional displays are processed at different stages. The aim is to give more insight about how the ability to detect emotions from their kinematics emerges during development. To do so, we chose the single point-of-light displays technique (Viviani & Stucchi, 1989; Viviani & Stucchi, 1992). This method of investigation was not used so far in the study of emotion comprehension, and therefore we chose to adopt a developmental course of investigation, adding a group of adults to two groups of 7- and 10-year-old children.

Secondly, the mu-rhythm desynchronization, previously described in response to observed actions, has also been widely investigated during the observation of emotional displays (Rayson, Bonaiuto, Ferrari & Murray, 2016). While traditionally the comprehension of emotional facial expressions has been investigated through static images, a growing body of studies is using dynamic facial expressions (Geangu, Quadrelli, Conte, Croci & Turati, 2016; Ruba & Repacholi, 2020; Segal & Moulson, 2020) to allow an observation closer to the everyday life: in ecological settings infants witness emotions developing in time through the activation of muscles of the face. In support of our view of a perception-action-emotion link, some studies even showed that with the observation of such facial emotional displays, infants activate the corresponding muscles in their own face (Geangu et al., 2016; Kaiser, Crespo-Llado, Turati & Geangu, 2017). In **Chapter 2**, the study ***Contagious smile: the observation of dynamic happy expressions activates sensorimotor areas in 7-month-old infants*** will focus on the question whether the observation of faces expressing different emotions in a dynamic rather than a static manner is able to generate activation of the sensorimotor cortex. Comparing angry and happy facial expressions, we sought evidence of a differential modulation of mu-rhythm desynchronization in response to static and dynamic emotional expressions at 7-months of life.

Thirdly, a more complex form of movement that we explored is the communicative setting of social interactions. As stated before, a fundamental part of human is being in relation and interaction with others. Action understanding takes place almost always in the context of interactions, in which meaning emerges from a dialogic engagement. Inter-actions could be therefore considered as a special case of actions (Reddy & Uithol, 2016), and a complete account of the action understanding development should take this into consideration. Within the first year of life, infants learn to anticipate other people’s behavior and plan their own actions accordingly (Sebanz, Bekkering & Knoblich, 2006; Striano & Stahl, 2005). This suggests that, when involved in first person in interactive situations, they form social scripts. Understanding this kind of interactive scripts is also essential for successfully taking part in such interactions (Gredeback & Melinder, 2010). Discriminating how others act is therefore extremely relevant: without an understanding of others' actions, their everyday interactions would be compromised (Henderson, Wang, Matz & Woodward, 2013). The study in **Chapter 3**, **Social interactions facilitate infant's learning of action-outcome associations** investigates how a specific movement performed from one person is associated with a response of a second person by 10-month-old infants. Action-outcomes associations are also compared in a similar but non-social setting, to further verify whether any possible effects found with the first paradigm can be ascribed to the facilitating social interaction, or whether the detection of contingency is enough to form complex associations.

Lastly, the possibility that actions directed towards objects are coordinated with a social message will be investigated. Indeed, the first three studies give their contribution in the domain of movement linked to social interactions and emotions. Infants, through this and many other cues, build a unified cognition that allows them to navigate the world in an efficient way. In doing so, they retain and use multiple sources of information. By the end of the first year, they use others' expressions (conveyed by both face and voice) to interpret external events and find causality between emotional expressions and environmental events (Moses, Baldwin, Rosicky & Tidball, 2001). Actions are therefore influenced by physical constraints as well as messages conveyed by others (Barna & Legerstee, 2005). But, to our knowledge, not much is known about the neural correlates of infants' early ability of linking others' emotional displays to their following actions. In the last chapter, we add to the complexity of the studies presented in the first three chapters, where only emotional information or interactive situations were presented. Here, we present a situation in which multiple elements are available to infants: first, different emotional information and secondly, alternative actions that could be performed on novel objects in daily interactions. The study presented in **Chapter 4,** ***The neural correlates of understanding emotion-dependent actions in 10-month-old infants,*** aims to investigate how the two actions of holding an object or pushing it away are processed at a neural level, and whether providing an emotional context in which those actions took place would alter their perception.

Altogether, in the theoretical framework of developmental cognitive neuroscience, the four studies use both behavioral (i.e., habituation, accuracy, reaction times) and electrophysiological (i.e., electroencephalography, event-related potentials, time-frequency analysis) measures to address some of the most important “dynamic aspects” of growing up, from learning how to interact with others through movement, to learning their emotions and how to regulate one’s own behavior according to those. Figure 2 briefly summarizes the structure of this thesis and the age groups that were involved.

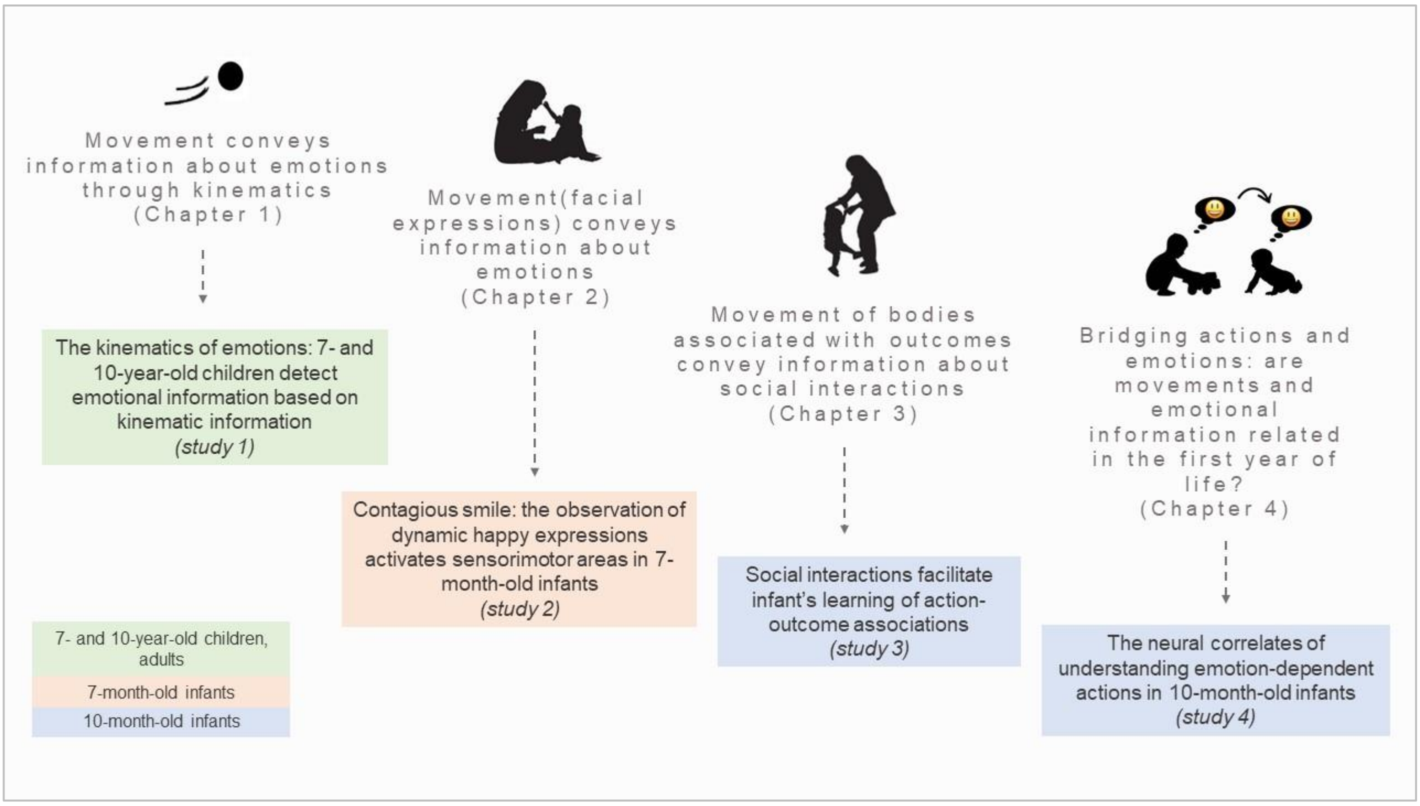

Figure 2. Structure of the studies presented in the thesis.

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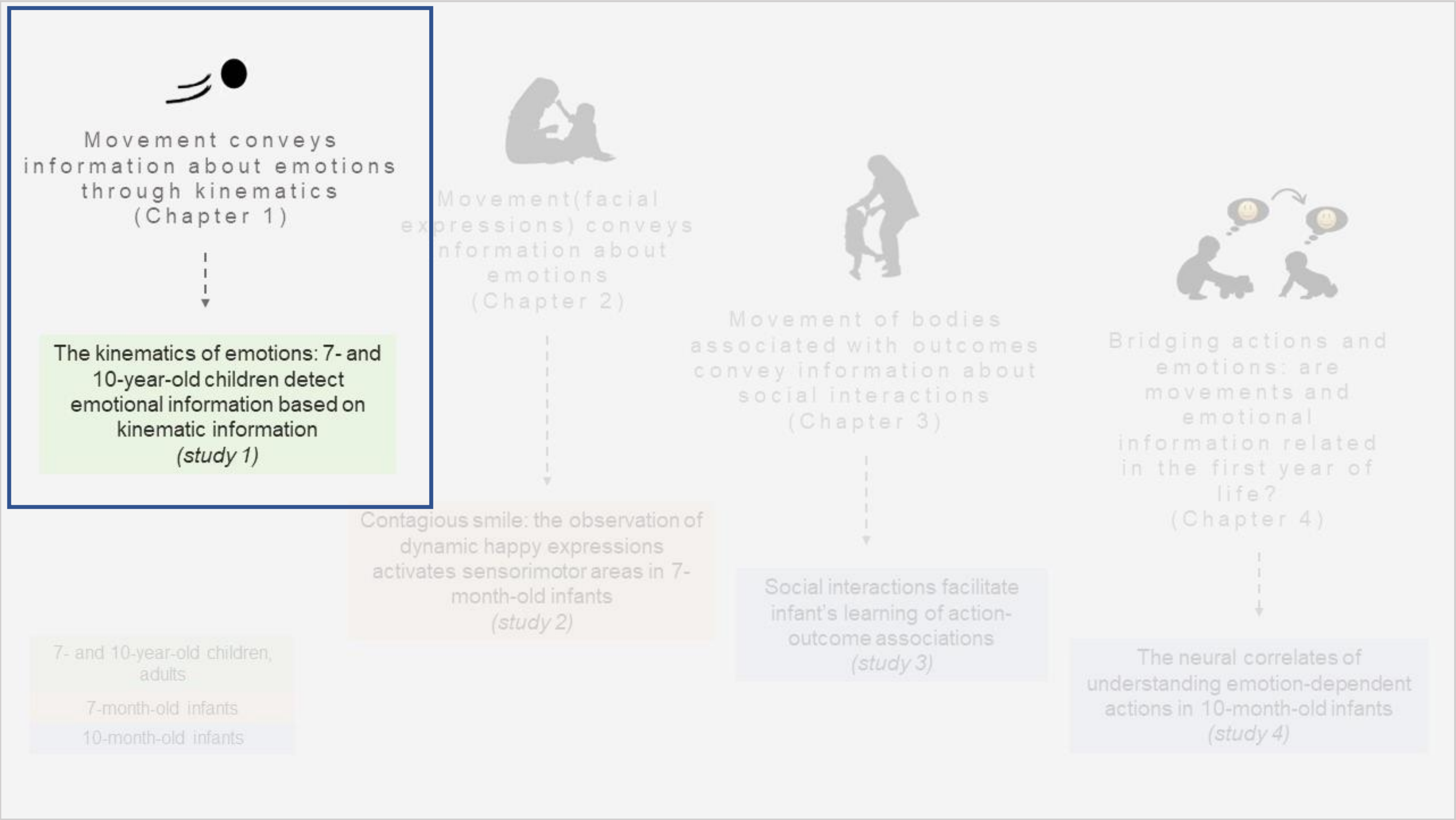
Chapter 1. Movement conveys information about emotions through kinematics.



The kinematics of emotions: 7- and 10-year-old children detect emotional information based on kinematic information (Study 1)[1].

Emotional information is everywhere in our daily life. Although it can be conveyed by a static display of the face (e.g., Richoz, Lao, Pascalis & Caldara, 2018; Nelson & Russell, 2011; Quadrelli, Conte, Macchi Cassia & Turati, 2019) or the body (Atkinson, 2013), it is much more powerfully encoded if conveyed also through movement (Caridakis et al., 2007; Atkinson, 2013).

This consideration led us to wonder what role of the kinematics per se has in emotions' comprehension. No studies, to our knowledge, previously approached this matter. Therefore, we chose to explore if simple animated shapes are recognized as conveying emotional valence by adults and two groups of primary school children (i.e., 7- and 10-year-olds). Children's accuracy in identifying displays with lower intensities has been found to develop between 7 and 10 years of age (Gao & Maurer, 2009; 2010), and we hypothesized that a similar developmental paradigm would be detectable also in the case of kinematic information.

"In the beginning was the Act". Goethe wrote these words in 1808 as part of his play *Faust*, giving origin to a proper revolution where the importance of actions was elevated to that of words and mind. In other words, we could say "I move, therefore I am", as opposed to the Cartesian "I think, therefore I am", emphasizing the idea that we acquire, through movement, experience about not only basic sensorimotor processes, but also more complex meta-representational processes such as agency, ownership of the body, beliefs and emotions (Synofzik, Vosgerau & Newen, 2008). In particular, the latter are a valuable resource in navigating the social world. We experience different emotions in first person, we express them through verbal and non-verbal signals, and we widely modulate our cognitive processes relying on perceived and experienced emotions (Dolcos, Iordan & Dolcos, 2011).

Research on emotion recognition has largely relied on static stimuli, such as photographs of facial expressions, and only recently employed dynamic facial expression of emotions in adults

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[1] Parts of this chapter are included in Roberti, E., Actis-Grosso, R., Turati, C. (*In prep.*) The kinematics of emotions: 7- and 10-year-old children detect emotional information based on kinematic information.

(e.g., Richoz, Lao, Pascalis & Caldara, 2018), children (e.g., Nelson & Russell, 2011), and even infants (e.g., Heck, Hock, White, Jubran & Bhatt, 2016; Quadrelli, Conte, Macchi Cassia & Turati, 2019; Rayson, Bonaiuto, Ferrari, & Murray, 2016; 2017). It has been shown that such dynamic displays facilitate the recognition of basic emotions and have a larger ecological validity than the static ones (Atkinson, Dittrich, Gemmell & Young, 2004). Moreover, according to some authors (e.g., Ambadar, Schooler & Cohn, 2005), kinematic information could facilitate the recognition of the configural cues involved in emotional expressions, while other studies failed to support this supposed facilitation (Fiorentini & Viviani, 2011).

Kinematic information about emotions can be expressed not only through facial cues, but also, and more importantly with the whole body language: hands, voice, posture and gait contribute widely to their display (Atkinson, 2013). Dynamic cues, from both face and voice, are particularly relevant for emotion comprehension during development. For instance, it was found that 3 to 5-year-olds rely more on visual cues (face and posture) to correctly label emotions, than on auditory cues (Nelson & Russell, 2011). The point-light displays (PLDs) are a meaningful tool that has been used to investigate how the body per se conveys meaning. The nature of these highly degraded presentations of few illuminated points of light affixed to the major joints of a moving person’s body allows reducing form cues to a minimum (Johansson, 1973, 1975). Observers are able to extract a number of meaningful information from the displays, such as the gender of individuals (Kozlowski & Cutting, 1977), the familiarity of their gait (Cutting & Kozlowski 1977) and the perceptual features of actions, along with their consequences (Dittrich 1993). The information conveyed is also sufficient to identify personality traits (Heberlein, Adolphs, Tranel & Damasio, 2004). Basic emotions portrayed by body movements, both through Full-light and Point-light movies, can also be successfully decoded by adults (Atkinson et al., 2004). The accuracy in emotions’ comprehension from PLD kinematics is correlated to the comprehension of facial cues, at the point that Alaerts and colleagues (2011) suggest that the same process might be at play and generalized across facial and body emotion perception. The facial and body expressivity domains are therefore strictly intertwined, but the nature of their correlation remains a matter of debate.

Two effects are well documented in the literature: (1) the *happy face advantage*, which consists in happy faces being recognized more easily than other emotional faces, such as sad or fearful faces (Leppänen and Hietanen, 2003; Shimamura et al., 2006), and (2) the *anger superiority effect*, according to which it is easier to detect angry faces than happy faces, perhaps because of a preattentive, parallel search (Hansen & Hansen, 1988). To these effects, a third one for bodies was added by Actis-Grosso, Bossi & Ricciardelli (2015), the *happy body advantage*: both happy faces and happy PLDs seem to be recognized faster than all the other emotions, although not more accurately than angry faces and PLDs. The *anger superiority effect* (Hansen & Hansen, 1988) is therefore at play for both faces and bodies as well: it is easier to detect anger, a perceptually (and behaviorally) salient stimulus compared to fear and sadness. For the remaining emotions, fear and sadness, participants relied more on static faces to recognize sadness, but on PLDs to recognize fear, supporting the idea that static components of emotional faces and the dynamic components of body language might be differently involved in the recognition of different emotions.

The roots of our emotional development can be found early on: newborns discriminate happy from disgusted dynamic emotional expressions (Addabbo, Longhi, Marchis, Tagliabue & Turati, 2018), while infants at 4-9 months of age successfully discriminate facial expressions such as fear, happiness, anger, sadness and surprise (Caron, Caron & MacLean, 1988; Nelson, 1987; Serrano, Iglesias & Loeches, 1992; White et al., 2019; Ruba & Repacholi, 2019). Between 6 and 10 months of life infants develop the ability to categorize facial expressions despite changes in intensity (Ludemann & Nelson, 1988; Bornstein & Arterberry, 2003), across individual identities (Nelson, Morse & Leavitt, 1979; Nelson & Dolgin, 1985; Kotsoni, de Haan & Johnson, 2001) and sensory modalities (Palama, Malsert & Gentaz, 2018), thus being able to comprehend the communicative signals conveyed by emotions (Hepach & Westermann, 2013; Grossmann, 2010). Children's capacity to accurately recognize emotional expressions keeps increasing during childhood and adolescence (Harrigan,1984; Markham & Adams, 1992; Brechet, Baldy & Picard, 2009), in parallel with the anatomical and functional changes occurring in a network of brain areas, including the prefrontal cortex (PFC), the fusiform gyrus, the insula and the amygdala (Thomas, De Bellis, Graham & LaBar, 2007; Herba & Phillips, 2004). The earliest emotion that children are able to recognize accurately is happiness, followed by fear, sadness, anger, and then by surprise (Camras & Allison, 1985; Thomas et al., 2007).

Also, the ability of extracting emotional information from body displays, is well at play even during early development. Behavioral and neural evidence suggests that already in the first year of life infants learn to discriminate positive and negative emotional expressions of the body (Grossmann, 2015; Vaish et al., 2008). Zieber and colleagues (2014) first demonstrated 6-month-olds' ability to differentiate happiness and anger expressed through body movements, while Missana, Atkinson & Grossmann (2015), in an electrophysiological study using PLDs depicting happiness and fear, indicated that 8- but not 4-month-olds show a selective response to the orientation and specific emotion conveyed by body movement. After the first year of life, the developmental curve continues, as highlighted before in relation to emotional comprehension in general, all the way through adolescence. When it comes to different intensities of emotions expressed through facial expressions, explicit emotion-matching tasks allowed observing the trajectory of accurate matching in children from 4 to 15 years of age. Along with their age, their performance in identifying fear and disgust increased as well, while a smaller improvement was observed for sadness, happiness and anger (Herba, Landau, Russell, Ecker & Phillips, 2006). Within these broader differences, more specific tuning points can be identified. Children's accuracy in identifying a happy facial expression is adult-like by 5 years of age, although the accuracy in identifying displays with lower intensities seems to further develop between 7 and 10 years of age; for fearful faces the performance becomes adult-like only at 7 years and the accuracy in determining the intensity of fearful expressions starts to increase only for 10-year-olds (Gao & Maurer, 2009; 2010). Although one possible explanation of the differential development of emotions is a limit on visual acuity, that makes it difficult to detect fine details comprised in high spatial frequencies until 7 years of age (Maurer & Lewis, 2001), all studies seem to agree that sensitivity to happiness is the first to develop, followed by fear, sadness and anger. Nevertheless, these studies only considered information conveyed by facial expressions while, as previously discussed, the body also plays an important role. On this regard, PLDs maybe represent a crucial tool of investigation. The perception of a coordinated animal locomotion (i.e., biological motion) from a Point-light animation was initially found to be readily available to children aged 3 to 4 years (Mitkin & Pavlova, 1990). Later studies found that 5-month-olds were able to discriminate possible biomechanical motion from scrambled or inverted displays (Marshall & Shipley, 2009), and that even newborns as young as 2 days of life discriminate biological and non-biological motion, manifesting a preference for the former even with a highly unfamiliar depicted event: a walking hen (Simion, Regolin & Bulf, 2008). As for emotion recognition, when 4 to 17 years-old participants were asked to make a forced-choice as to which emotion was being portrayed by full-light and point-light video clips, a considerable increase in accuracy was observed at 8.5 years of age, and after this age the improvements would continue, although at a slower rate, for all adolescence (Ross et al., 2012).

Overall, despite the large amount of literature dedicated to the investigation of development of children's ability to detect biological motion from PLDs and recognize emotional expressions, no studies so far examined how the ability to detect emotions from their kinematics emerges during development. The present study presented a forced choice paradigm to 7 and 10-year-old children to investigate their accuracy in recognizing happiness and fear from movement. PLDs, although simplified versions of a body's movement, still contain a lot of pictorial information from which cues about emotional displays could be detected. Although classically PLDs have been used to separate information concerning motion from any other type of visual information (Simion, Regolin & Bulf, 2008), PLDs technique might not completely separate the kinematic component from configural information, given that some information related to shape could be extracted, due to the motion coherence of the visible moving points (Wertheimer, 1923), Motion coherence is widely recognized as the base for the ability to perceive the 3-D shape of objects solely from motion cues, which has been referred to as structure-from-motion perception (Grunewald, Bradley & Andersen, 2002). Following this line of reasoning it is not surprising that dynamic emotional faces are better recognized than static ones, given that more information is available for the perceptual system, which could rely on both static and dynamic cues in a three-dimensional manner.

To better disentangle configural information from purely kinematic one, we chose to adopt another emerging method of investigation: the single point-of-light displays (Viviani & Stucchi, 1989; Viviani & Stucchi, 1992), that move following the ‘‘two-third-power law’’. This law describes movements typical of the human body as having a peculiar curvature and tangential velocity, together with a speed following elliptical paths perceived as uniform: the tangential velocity can be up to tripled between points of maximum and minimum path curvature, and yet appear constant (Viviani & Stucchi, 1992). Even 4-day-old newborns, tested with a preferential-looking paradigm, have shown to look longer at the non-biological motion, suggesting that the movement in which the ‘‘two-third-power law’’ is not respected violated their expectations (Méary, Kitromilides, Mazens, Graff & Gentaz, 2007). We thought that it should therefore be possible to identify the specific kinematics related to specific emotions, so that a single point of light (or a meaningless geometrical form) could be perceived as happier or sadder, in analogy with classical studies on animacy (Heider & Simmel, 1944; Salva, Mayer & Vallortigara, 2015), helping in this way to better clarify the link between the perception of emotions and the perception of motion.

We included children of 7 and 10 years because these ages were documented in the literature as moments in which accuracy in identifying emotional displays increases significantly (Gao & Maurer, 2009; 2010; Ross et al., 2012). We hypothesized a similar developmental trajectory in the case of kinematic information. Given the novelty of this method in the study of emotion comprehension, an adult sample was also included as a term of comparison for the children’s sample.

Methods

Participants

The final sample consisted of 30 adults (mean age = 25.78 years, SD = 4.35 years, 9 males), 30 10-year-olds (mean age = 9.69 years, SD = 4.15 months, 16 males) and 30 7-year-olds (mean age = 7.31 years, SD=3.78 months, 14 males). Adult participants were students recruited in the University of Milano - Bicocca. Child participants were recruited in the suburban areas of Milano and Lecco, and they were reported from the teachers to not have any history of neurological or significant medical condition. All participants had normal or corrected to normal vision. An additional 19 children were tested (*N*=10 7-year-olds, *N*=9 10-year-olds), but excluded from the final sample when the consent from the parents was not given (*N*=3), if they were younger than the target age group (*N*=9 7-year-olds and *N*=6 10-year-olds) or did not complete the procedure (N=1).

Prior to the testing sessions, all adult participants and parents gave their written informed consent, while verbal consent was obtained for the 7- and 10-year-olds, according to the ethical standards of the Declaration of Helsinki (BMJ 1991; 302:1194). The ethics committee of the University of Milano - Bicocca approved the study (protocol n. 395).

Stimuli

The set of stimuli consisted of videos in which a single animated geometrical shape on a black background moved conveying a happy, a fearful, or a neutral emotion. The neutral animation was designed followed a Translational trajectory, to convey a movement that would not be associated to any emotional expression. The emotional animations were created from a selection of cartoons, in which the character (e.g., Tom & Jerry) displayed a fearful or a happy emotion through a Wave-like body movement for the positive emotion and a Parabolic trajectory for the negative emotion. Individual frames were extracted using the software Virtual Dub 1.9.11 (http://www.virtualdub.org) and then imported in a Microsoft PowerPoint 97-2003 presentation. A geometrical form was added to each frame and aligned to the top-left point in the character's body that was then removed from the scene. This procedure allowed to preserve only the kinematic cues, while all other pictorial emotional information (i.e., facial expressions and posture) were removed. In order to make the task more interesting and diverse for children, the moving geometrical form expressing each emotion (happy, fearful and neutral) was presented in 3 different shapes (circle, square, triangle), 2 different colours (white, yellow) and could start its movement from the 2 sides of the screen (left, right), for a total of 36 videos. Square's sides were of 128 pixels, triangle's sides were of 126, 140 and 140 (height: 124) pixels and the circle had a diameter of 126.81 pixels. The luminance of the videos was checked with a Minolta CS-100 photometer for the two colours presented. The yellow animation had a luminance of 90.4 cd/m^2 and the white animation had a luminance of 108 cd/m^2.

All the three movements started with an initial entry motion that followed a linear path, and ended with final backward motion, in which, after reaching the three quarters of the screen, the geometrical shape turned around and went back from the same path. The total length of each video was of 3 seconds. *(a) Fearful motion* (Figure 1, panel a). After an entry motion of 861 pixels, the shape "jumps" (with a parabolic trajectory) and start "shaking". The jump started from a velocity of 0.14 m/s (the same of the entry motion) and had a linear acceleration until it reached the top of the vertical trajectory (184.6 pixel in height). At the top of the jump the square moved back-and-forth along a small horizontal trajectory of 139.4 pixels (i.e., "shaking behaviour) for five times, and then moves downward to go back along a horizontal trajectory of 861 pixels, with a higher velocity (i.e. 0.24 m/s) and a constant acceleration. *(b) Happy motion* (Figure 1, panel b). After an entry motion of 664 pixels, the shape started "jumping" in a sequence of five jumps following a wave-like trajectory. Each jump started from a velocity of 0.17 m/s (the same of the entry motion) and had a linear positive acceleration until it reached the top of the vertical trajectory (82 pixel in height for the first jump, then 158.2, 113, 219.7 and 141.8 pixel respectively) and a linear negative acceleration when it went down. After the jumps the shape moves backward, following a linear path of 764.7 pixels with a constant velocity of 0.19 m/s. (c) *Neutral* video (Figure 1, panel c). After an entry motion of 748 pixels, the shape went upward along a 65-degree tilted trajectory, then it went downward and moved for 403.9 pixels to start an "inverse" jump (i.e., downward first), after which it went along a small horizontal path of 231 pixels and then turns backward along a horizontal path of 527.3 pixels. The whole motion had a constant velocity of 0.16 m/s.

The distribution of angular velocity between each frame and the next frame of the different videos did not significantly differ when performing a Wilcoxon signed-ranks test comparing fear (M = 0.19 m/s; SD = 0.11 m/s) and happiness (M = 0.18 m/s; SD = 0.09 m/s), or happiness and neutral (M = 0.16 m/s; SD = 0.10 m/s) (both *p*>.09), while the neutral animation resulted to be slower than the fearful one (Z = -2.93; *p* = .004, d = 0.28).

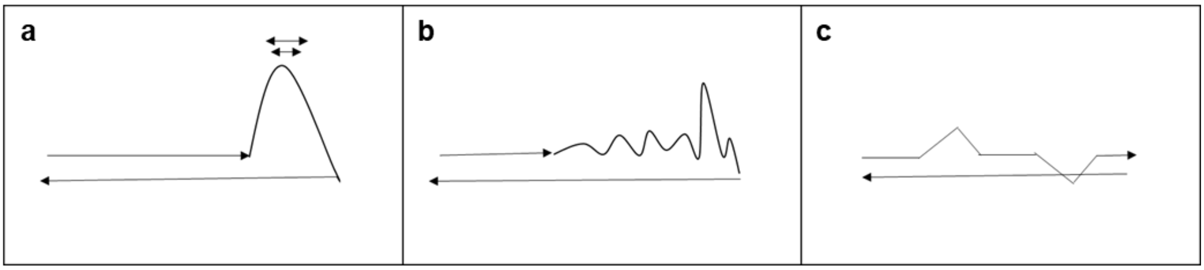

Figure 1. Trajectories for the fearful (a), happy (b) and neutral (c) stimuli. (a) After a Translational entrance, the shape jumps, shakes and goes back down following a Parabolic course; (b) the shape jumps following a Wave-like motion; (c) a neutral Translational series of movements.

This difference is expected, but a Mann-Whitney test also showed that the distribution of values between the angular acceleration values in the three videos did not differ (all $p>.72$) (Figure 2). Therefore, in average, no video contained more accelerating or slowing down movements than the others (mean acceleration: neutral: -0.24 m/s^2; fear: -0.03 m/s^2; happiness: 0.11 m/s^2).

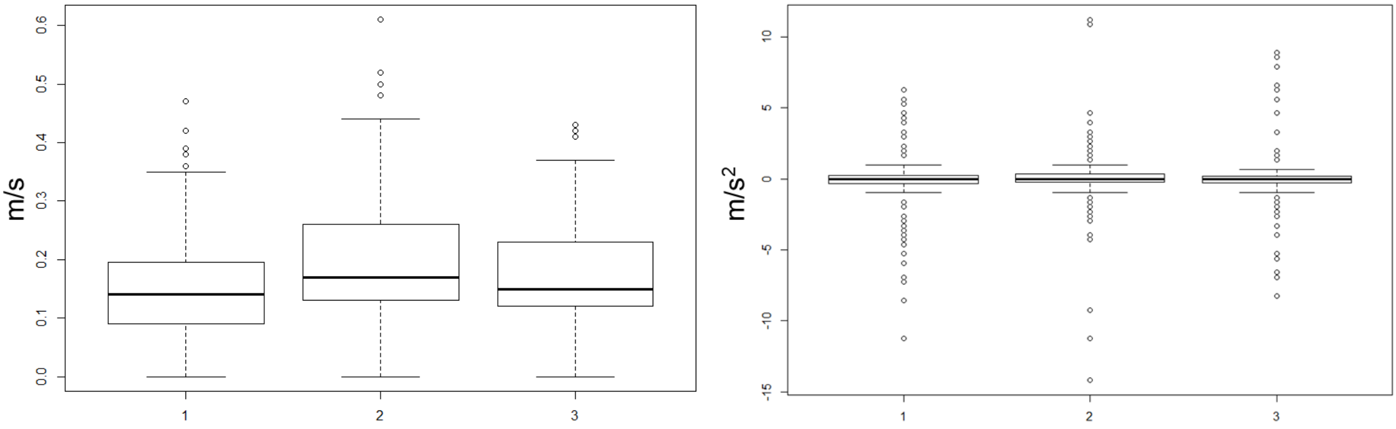

Figure 2. Boxplot for the speed distributions (left) and acceleration distribution (right) for neutral (1), fearful (2) and happy (3) video stimuli.

Design and procedure

Participants sat on a chair in front of a desk, at a distance of approximately 75 cm to the computer screen. They were told that they would see some short videos of geometrical shapes. The task required to categorize each video, as quickly and as accurately as possible, by clicking with the mouse on one out of two emoticons, displayed at the upper left and right corners of the computer screen. The emoticons displayed could be happy and neutral, happy and fearful, fearful and neutral, counterbalanced within participants as their left/right corner position (Figure 3).

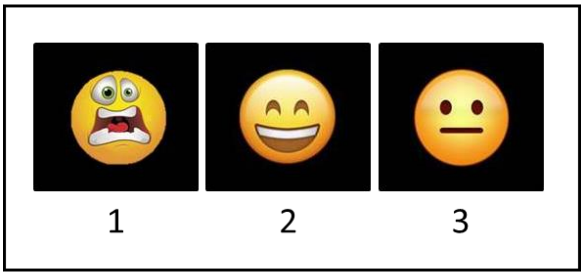

Figure 3. Displayed key responses for the fearful (1), happy (2) and neutral (3) condition. All the response buttons had the same dimension (1.43 x 1.29 cm) and were aligned to the top left and right corners of the screen.

Six practice trials were administered before starting the experimental session. In order to start each trial, participants had to press a “Start” button located at the bottom-centre of the screen, which was followed by the videos, presented centred to the screen (Figure 4). The order of videos presentation was randomized and, in order to give children the chance to take breaks if needed, the stimuli were organized in three blocks of 12 videos each. All participants completed all three blocks, for a total of 36 trials, in average in 7 minutes (SD = 1.24 min). A Dell computer with a 15.6-inch screen connected via USB to a mouse was used for data collection. A Mouse Tracker software (Freeman & Ambady, 2010) was used. The mouse speed was set to the middle setting of Windows 7 (as in Hermens, 2018).

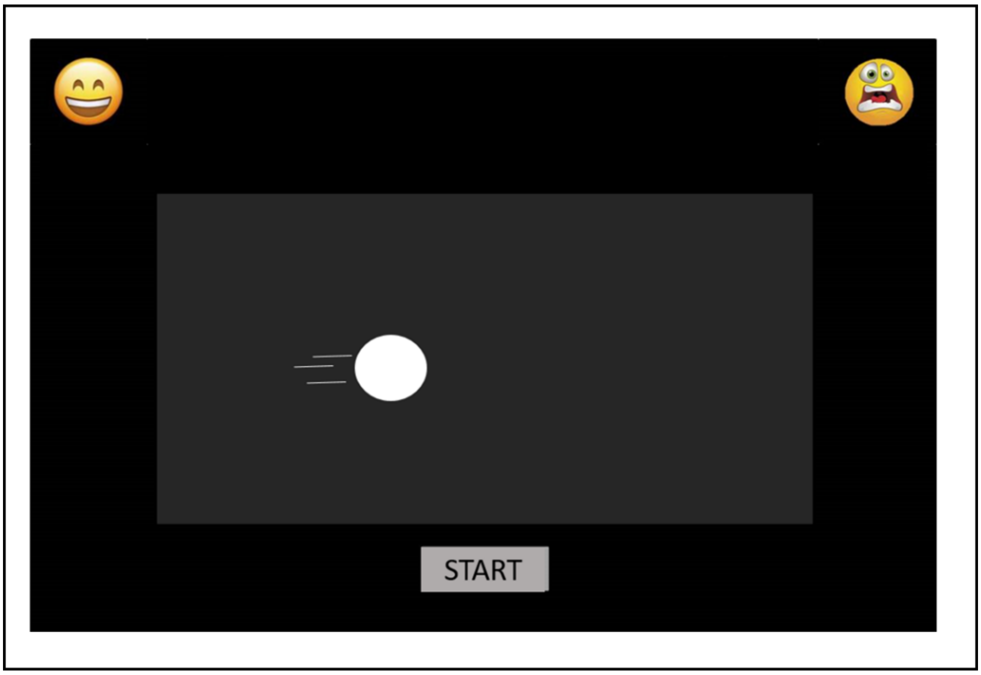

Figure 4. Visual display of the experimental procedure, presented with Mouse tracker. Participants pressed the “Start” button and the videos, appeared at the center of the screen. They were instructed to press the response button that better represented the emotional category of the stimuli by clicking a mouse button. After the response was give, another “Start” button appeared, in order to begin the following trial. No feedback on the accuracy was given to the participants.

Data analysis

Accuracy was calculated for all age groups by dividing the number of correct answers for the total of the presented trials for each condition (i.e., happiness, fear, neutral). Reaction times (RT) inn milliseconds starting from the onset of the videos to the moment when a response was given were recorded by the mouse-tracker and analysed. The mouse-tracker software also extracts measures of attraction towards the two alternative emoticons displayed in the top corners of the computer screen. Specifically, we analysed the maximum deviation (MD) calculates as the largest perpendicular deviation between the mouse movement and the straight trajectory from the start to the end point, and area-under-the-curve (AUC), the geometric area between the mouse movement and the straight idealized trajectory. (Freeman & Ambady, 2010). In first instance, data were checked for outliers in reaction times, calculated as exceeding the 2 standard deviations from the mean criteria. The trials in which an outlier was found were excluded from further analyses (trials per subject in the adult sample: M=0.88; SD = 1.00; in the 10-year-olds sample: M=0.66; SD = 0.97; in the 7-year-olds sample: M=0.44; SD = 0.78). Accuracy scores were then calculated for each participant, per each category and one-sample t-test were performed to make sure that the accuracy scores significantly differed from a 50% chance of response. In the adult sample, participants' accuracy was significantly different than the 0.5 chance level, for the happy, (*M* =0.83; *SD* =0.20) *t* (29) = 7.57; *p* <.001, *d* = 1.20, fearful, (*M* = 1; *SD* =0.29) *t* (29) = 6.56; *p* < .001, *d* =1.38, and neutral condition, (*M* = 0.76; *SD* = 0.24) *t* (29) = 6.13; *p* <.001, *d* =1.12. In the 10-year-olds sample the same was found, with high accuracies for the happy, (*M* = 0.70; *SD* = 0.20) *t* (29) = 5.43; *p* <.001, *d* = 1.21, fearful, (*M* = 0.83; *SD* = 0.27) *t* (29) = 6.63; *p* < .001, *d* = 0.99, and neutral condition, (*M* = 0.62; *SD* = 0.18) *t* (29) = 3.71; *p* <.001, *d* = 0.67. For the 7-year-olds, this was true for the fearful, (*M* = 0.75; *SD* = 0.29) *t* (29) = 4.73; *p* < .001, *d* = 0.86, and neutral condition, (*M* = 0.61; *SD* = 0.21) *t* (29) = 2.93; *p* =.007 , *d* = 0.53, while for the happy condition the accuracy was not significantly different than chance, (*M* = 0.58; *SD* = 0.25) *t* (29) = 1.76; *p* = .089 , *d* = 0.32.

Therefore, except for the happy stimuli in the 7-year-olds group, the stimuli presented were accurately recognized at all ages, supporting the validity of the stimuli set towards communicating the expected emotional valence or absence thereof. A 3 x 3 repeated measures analysis of variance (ANOVA) was performed with the three categories as within-subjects factor and age groups as between-subject factors, to check if the accuracy between age groups differed. As expected, there was a significant effect of emotion, *F* (2, 206) = 9.19, *p* < 0.001, η_p^2 = 0.08. Post-hoc tests showed that fear's accuracy (*M*= 0.86; *SD* = 0.28) was higher than both the happy (*M* = 0.83; *SD* = 0.22) and the neutral accuracy (M = 0.66; SD = 0.21). An effect of age group was also found, *F* (2, 103) = 11.7, *p* < 0.001, η_p^2 = 0.19). Post-hoc tests showed that adults' accuracy (*M*= 0.86; *SD* = 0.24) was higher than both the 10-year-olds (*M*= 0.72; *SD* = 0.22) and the 7-year-olds (*M*= 0.65; *SD* = 0.25), and that 10-year-olds accuracy was higher than the one of 7-year-olds (all *p*<.04). No emotion x age interaction was observed in accuracy values (*p* = 0.29).

After excluding trials in which an incorrect response was given or the reaction time exceeded the 2 standard deviations threshold, a mean of 27.8 (*SD* = 6.4) trials per participant were included in the final analyses for the adult sample, a mean of 24.7 (*SD* = 5.2) for the 10-year-olds sample, and a mean of 22.4 (*SD* = 5.9) trials for the 7-year-olds. Considering incorrect responses and outliers, a mean of 2.73 trials (*SD* = 3.09) was eliminated in the adult sample, a mean of 3.78 trials (*SD* = 2.78) in the 10-year-olds sample and a mean of 4.53 trials (*SD* = 2.95) in the 7-year-olds sample.

A 2 x 3 x 2 repeated measures analysis of variance (ANOVA) was performed for each age group with colour (white, yellow), shape (circle, square, triangle) and direction of the movement (left, right) as within-subject factors, to make sure that these factors did not affect the responses to the task. As expected, for all age groups the only significant effect was emotion (all $p<0.02$), while no effect of colour, shape, direction and no interactions were found (all $p>0.09$). Therefore, these factors were collapsed for further analyses.

For each participant, a RT, MD and AUC score was then calculated for the 3 emotions (happiness, fear, neutral). Given that data were distributed normally (Shapiro-Wilk $p>0.05$), separate ANOVAs were computed for the 3 dependent variables, with emotion as within subject factor and age group (adults, 10-year-olds, 7-year-olds) as between-subject variable. Pairwise t-test comparisons, where necessary, were conducted using a Bonferroni correction. The significance threshold was set at 0.05, and a Greenhouse-Geisser correction was applied whenever the assumption of Sphericity was violated (indicated by ε).

Results

Reaction time (RT)

A main effect of emotion, F (1.44, 125.61) = 17.25, $p < 0.001$, $\eta_p^2 = 0.17$, $\varepsilon = 0.72$, and age group, F (2, 87) = 58.5, $p < 0.001$, $\eta_p^2 = 0.57$, were observed. Bonferroni-corrected post-hoc tests showed that RTs in the fearful condition (*M*= 5276 ms; *SD* = 1151) were lower than in both the happy (*M*= 5840 ms; *SD* = 1660 ms) and the neutral (*M*= 5794 ms; *SD* = 1304) condition (all *p*<.001). The happy and the neutral condition, in contrast, did not differ from each other (p > 0.9) (Figure 5).

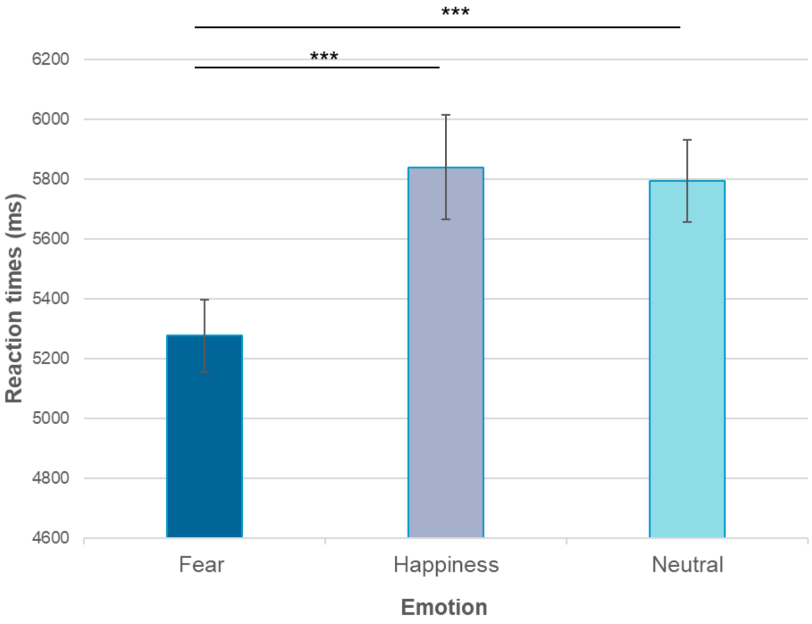

Figure 5. RTs observed for the different emotions across age groups. In the fearful condition (*M*= 5276 ms; *SD* = 1151 ms) RTs were lower than in both the happy (*M*= 5840 ms; *SD* = 1660 ms) and the neutral (*M*= 5794 ms; *SD* = 1304 ms) condition (all *p*<.001). The happy and the neutral condition, in contrast, did not differ from each other (*p* > 0.9).

The Age group main effect indicated that adults (*M*= 4561 ms; *SD* = 185) were faster than 10-year-olds (*M*= 5482 ms; *SD* = 363) and 7-year-olds (*M*= 6866 ms; *SD* = 420), and 10-year-old children were also significantly faster than the 7-year-old children (all *p*<.001) (Figure 6).

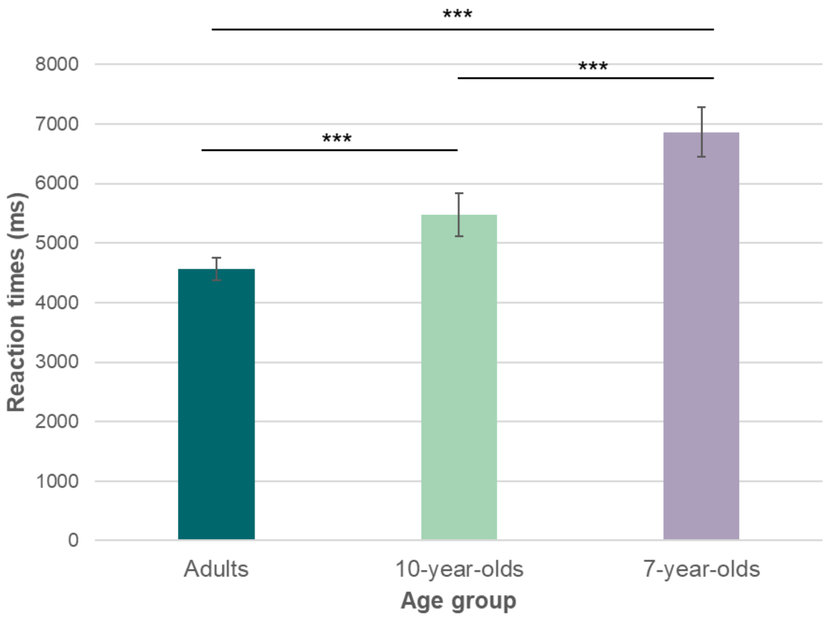

Figure 6. RTs observed for the different age groups across emotions. Adults (*M*= 4561 ms; *SD* = 185 ms) were faster than 10-year-olds (*M*= 5482 ms; *SD* = 363 ms) and 7-year-olds (*M*= 6866 ms; *SD* = 420 ms), and 10-year-old children were also significantly faster than the 7-year-old children (all *p*<.001).

To further investigate the differences between responses to emotions in the groups, three separate ANOVAs were carried out. In the adult group, the pattern found in the mixed ANOVA was confirmed, *F* (2, 58) = 8.66, *p* < 0.001, η_p^2 = 0.23, with lower RTs in the fearful condition compared with the happy, *M* = −350.9 ms, *SD* = 89.3; *t* (29) = −3.93, *p* < 0.001, and the neutral condition, *M* = −281 ms, *SD* = 89.3; *t* (29) = −3.15, *p* = 0.008. The same pattern was found for 10-year-olds, *F* (2, 58) = 25.5, *p* < 0.001, η_p^2 = 0.47, with lower RTs in the fearful condition compared with the happy, (*M* = −522 ms, *SD* = 102), *t* (29) = −5.14, *p* < 0.001, and the neutral condition, (*M* = −698 ms, *SD* = 102), *t* (29) = −1.73, *p* < 0.001. For the 7-year-olds, although the general effect of emotion was still present it had a small effect size, *F* (2, 58) = 4.20, *p* = 0.02, η_p^2 = 0.12, and the paired-sample t-test revealed that fear only differed from happiness, (*M* = −818 ms, *SD* = 290), *t* (29) = −2.82, *p* = 0.019 (Figure 7).

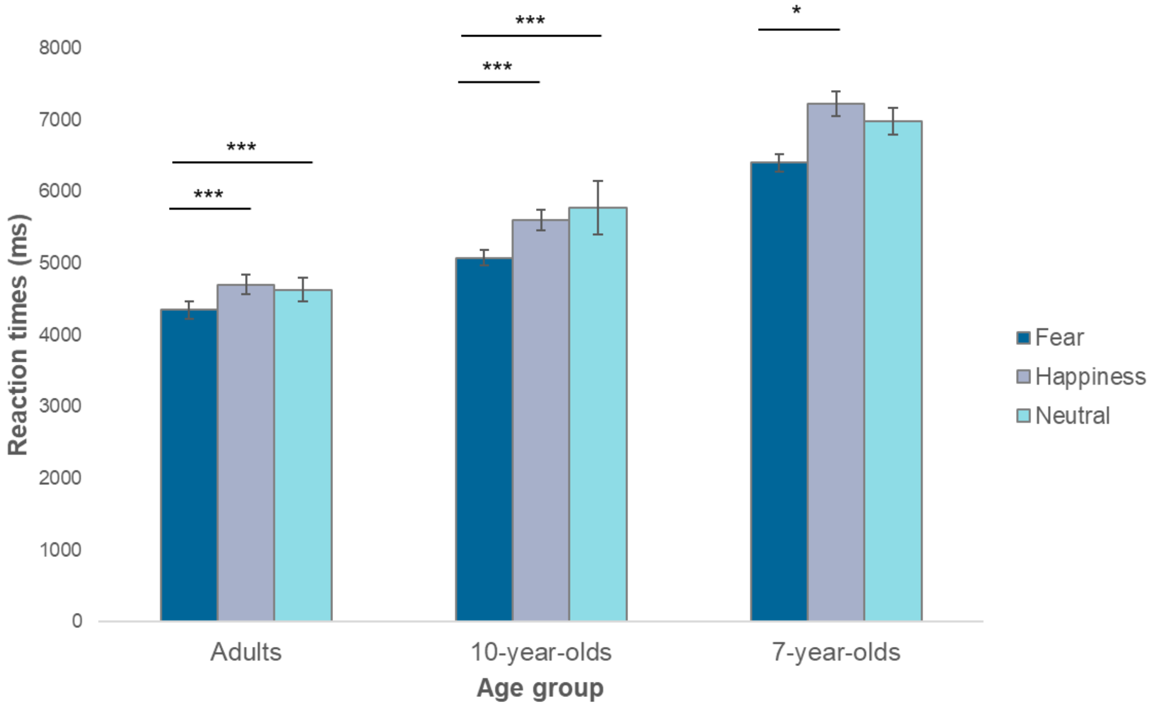

Figure 7. Three separate ANOVAs revealed in the adult group, lower RTs in the fearful condition compared with the happy (*M* = −350.9, *SD* = 89.3; *t* (29) = −3.93, *p* < 0.001) and the neutral condition (*M* = −281, *SD* = 89.3; *t* (29) = −3.15, *p* = 0.008). In the 10-year-olds, lower RTs were observed in the fearful condition compared with the happy (*M* = −522, *SD* = 102; *t* (29) = −5.14, *p* < 0.001) and the neutral condition (*M* = −698, *SD* = 102; *t* (29) = −1.73, *p* < 0.001). In the 7-year-olds, lower RTs were observed for fear compared with happiness (*M* = −818, *SD* = 290; *t* (29) = −2.82, *p* = 0.019).

Area-under-the-curve (AUC) and maximum deviation (MD)

The ANOVA with AUC as dependent variable revealed a significant interaction between emotion and age group, *F* (4, 174) = 2.97, *p* = 0.021, $\eta_p^2 = 0.06$. In order to further investigate this interaction, post-hoc comparisons were conducted and revealed that, for the 10-year-old sample, the area between the actual mouse movement and the straight idealized trajectory was smaller for fearful than for neutral responses, (*M* = -0.47, *SD* = 0.13), *t* (29) = −3.5, *p* = 0.021.

A similar pattern was also evident when considering the second measure provided by Mouse Tracker, the largest perpendicular deviation between mouse movement and the straight trajectory (MD). In this case, a main effect of emotion, *F* (2, 174) = 3.86, *p* = 0.023, η_p^2 = 0.04, was further qualified by the interaction between emotion and age group, *F* (4, 174) = 4.11, *p* = 0.003, η_p^2 = 0.09. Again, for the 10-year-olds, the largest perpendicular deviation of the mouse was smaller for fearful than for neutral responses, (*M* = -0.18, *SD* = 0.05), *t* (29) = −3.5, *p* = 0.019 (Figure 8). The similarity in AUC and MD findings reflects the fact that both these measures allow to analyse, through hands' observed movements, the continuous unfolding of cognitive processes during the execution of a behavioural response (Freeman, Dale & Farmer, 2011).

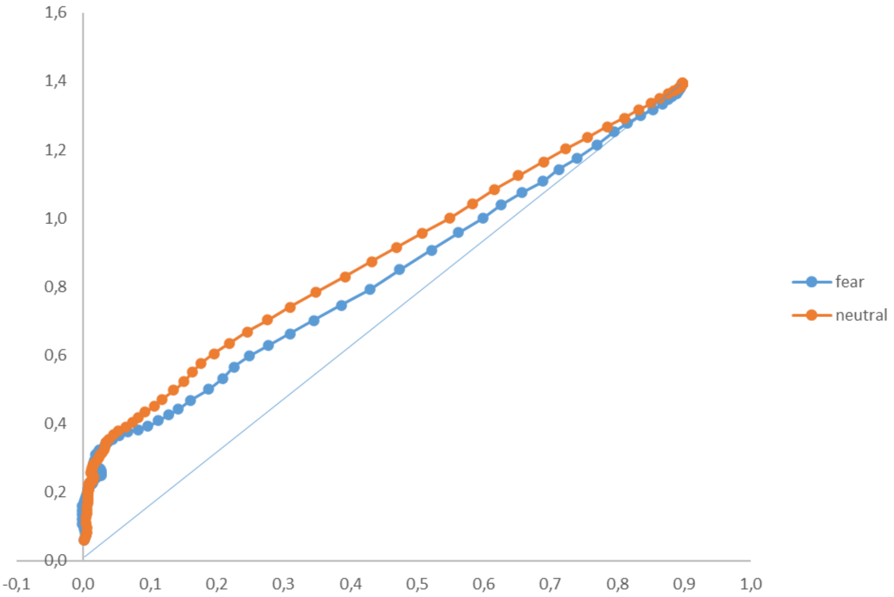

Figure 8. AUC and MD, Mouse Tracker indexes of the strength of attraction towards the alternative response. Both revealed that, for the 10-year-old sample, the area between the actual mouse movement and the straight idealized trajectory was smaller for fearful than for neutral responses (AUC: M = -0.47, SE = 0.13; t (29) = −3.5, p = 0.021; MD: M = -0.18, SE = 0.05; t (29) = −3.5, p = 0.019).

Discussion

The study of emotion recognition's development has been extensive, and its focus was predominantly on faces (Richoz et al., 2018; Nelson & Russell, 2011; Heck et al., 2016; Quadrelli et al., 2019; Rayson et al., 2016; 2017) and bodies (Atkinson, 2013; Atkinson et al., 2004; Actis-Grosso et al., 2015). Such studies describe dynamic cues as facilitating the recognition of emotional expressions in adults (Richoz et al., 2018), children (Nelson & Russell, 2011), and infants (Heck et al., 2016; Quadrelli et al., 2019; Rayson et al., 2016; 2017). Nonetheless, in dynamic faces the kinematic, configural information are all present (Ambadar, Schooler & Cohn, 2005). Some studies also described the body as conveying emotions by using PLDs, where kinematics plays an important role although, again, this is not the only element at play. The aim of our project was to determine whether the kinematics per se could be a source of information on others' movements and emotions. Since PLDs still present some pictorial information about bodies, we simulated emotional movements (happy and fearful in particular) through a single point moving, following the lead of the single-point studies modelled on the ''two-third-power law'' (Viviani & Stucchi, 1992; Méary et al., 2007; Scheerer, 1984, 1987). Our hypothesis was that we would find some differences amongst the different emotional and non-emotional motions, and we also explored the possibility of a developmental pattern across two groups of children (7- and 10-year-olds) and a group of adults.

Collected data showed that at all ages, both emotional (happy and fearful) and neutral animations are correctly identified (although 7-year-olds seem to have more difficulties with the happy movement), and that at all ages fear is recognized faster than both happiness and neutral movement for adults and 10-year-olds, and only faster than happiness for the 7-year-old children. These results suggest that kinematics contributes in different measure to the comprehension of different emotions. While to recognize happiness kinematic does not appear to be a fundamental cue, it would be for the identification of fear, supporting the idea that static and the dynamic components of body language might be differently involved in the recognition of different emotions (Actis-Grosso, Bossi & Ricciardelli, 2015).The present study was, to our knowledge, the first in studying the kinematics of emotions with a technique that allows an elimination of all the perceptual and, in particular, configural information present in both faces and point-light displays. The above mentioned "two-third-power law" describes movements typical of the human body as having a peculiar curvature and tangential velocity, together with a speed following elliptical paths perceived as uniform (Viviani & Stucchi, 1992). Based on this line of evidence, we thought that it should be possible to identify the specific kinematics related to specific emotions, so that a single point of light (or, as in our case, a geometrical shape) could be perceived as happy or fearful, in analogy with classical studies on animacy (Heider & Simmel, 1944; Wagemans, Van Lier, & Scholl, 2006). Indeed, our results are a first step in this direction. Interestingly, they also suggest a facilitation for the recognition of fearful stimuli.

As laid out in the introduction, the literature describes two effects for the recognition of emotional facial expression, the *happy face advantage* (Leppänen & Hietanen, 2003; Shimamura et al., 2006), and the *anger superiority effect* (Hansen & Hansen, 1988). As for bodies, Actis-Grosso and colleagues (2015), described the *happy body advantage* since both happy faces and happy PLDs are recognized faster than the other emotions. PLDs were also described as essential towards recognizing fear (Actis-Grosso et al., 2015). The results of the present study build on this last observation adding a further element: fear is not simply conveyed through PLDs, but more importantly through their kinematics. The fact that a happiness advantage is not detected through the kinematics alone might be due to the configural information that was still available in the displays, leading to think that this was an essential cue towards their recognition.

One limit of this study is that the movement that the shapes follow is extracted from cartoons adapting it to the three specific motion patterns (i.e., Translational, Parabolic and Wave-like) that have been associated with different emotions displayed by faces (Chafi et al., 2012; Podevin, 2009). To our knowledge, only one study employed the same trajectories in the study of emotional movies. Adult participants were shown short films in which a black disk was superimposed to the characters, so that only the motion patterns were visible (Chafi, Gambet, Crespel, Schiaratura & Rusinek, 2014). These videos only depicted a positive or a negative affect (without further specifications). Data suggested that the translational motion only increased induced feelings of happiness and agitation (while it is usually associated with neutral motion). This result might have possibly been due to the broader difference between positive and negative affect in the video selection. Nonetheless, our results might fail to identify a happy kinematics advantage because we relied on a wave-like pattern for happiness and not a translational one. Further studies should assess this possibility by adding a condition in which happiness is expressed through translational movement. Moreover, the choice of motion pattern would be better justified through the study of differences in amplitude, frequency, and phase of the relevant harmonics (Barliya et al., 2013). Only a similar analytical model of motion types based on geometric and mathematical laws would be able to confirm which pattern allows a better comprehension.

Furthermore, we observed that the distinction between happiness and a neutral movement was more difficult. Although this remark is in line with previous literature (Ikeda & Watanabe, 2009), one noteworthy aspect that we noticed during stimuli creation, is that children’s cartoons seem to underrepresent happiness expressed through body movements. Many more exemplars of fearful moving characters were observed, with different degrees of intensities. Although this is merely an observation originated by our investigations, we believe it would be very interesting to have a systematic analysis of cartoons and videos specifically designed for children to further explore this aspect.

One last point that rose from our results and is worthy of attention, is that only for the 10-year-olds the mouse tracking variables (AUC and MD) showed a straighter trajectory for fear identification. These measures reflect real time decision making and how this changes motor programmes (Freeman & Ambady, 2010). We believe that this is due to the fact that 10-year-olds, as 7-year-olds, tend to start moving the mouse before the emotion is identified, but then they are quicker in the decision-making process, in particular for fear (Figure 9). Adults on the other hand, are more aware that the movement towards the response button is subordinated to the labelling of the emotion, and therefore probably start all actions only after a decision is made. Hence, no differences are observable.

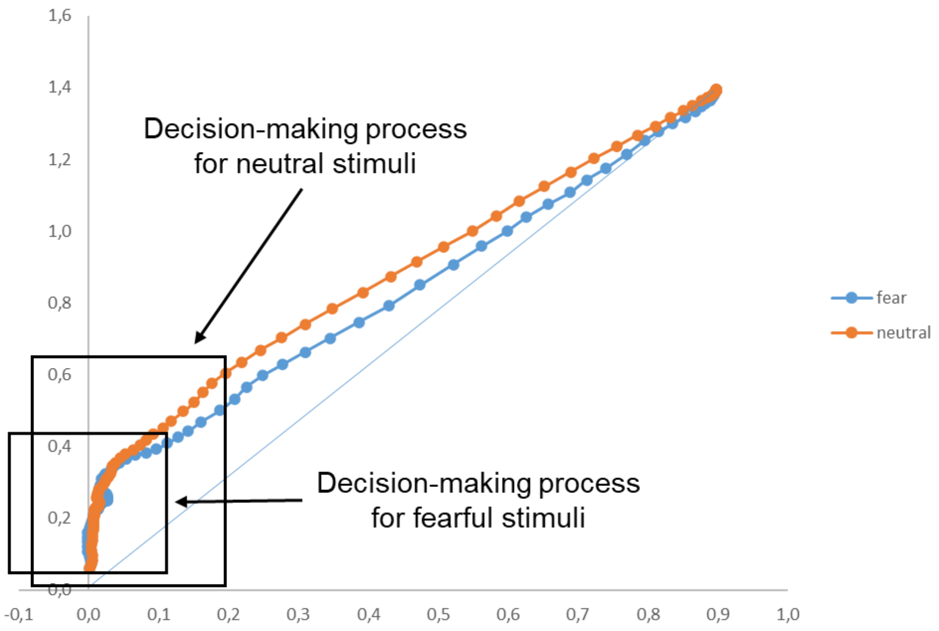

Figure 9. AUC and MD, Mouse Tracker indexes of the strength of attraction towards the alternative response (already presented in Figure 8), show that for the 10-year-olds, the decision-making process is quicker for fear, as reflected by their motor program updated online.

In conclusion, the present study explored the possibility that different emotions can be extracted from the kinematics of movements alone. The results seem to be promising and indicate that, although all types of movement can be accurately identified, fearful kinematics provides particularly rich information that is quickly interpreted by all age groups. Moreover, a developmental trajectory seems to suggest that this ability is not innate but rather acquired with experience. Further studies are needed to determine how early the onset is and what mechanisms are at play.

This chapter showed that the kinematics alone is a promising tool of investigation in the direction of emotional comprehension of school-aged children. In the next chapter another level of motion will be addressed: the one of facial expressions. Facial expressions are indeed the most informative source of information for infants in the first stages of their emotional development.

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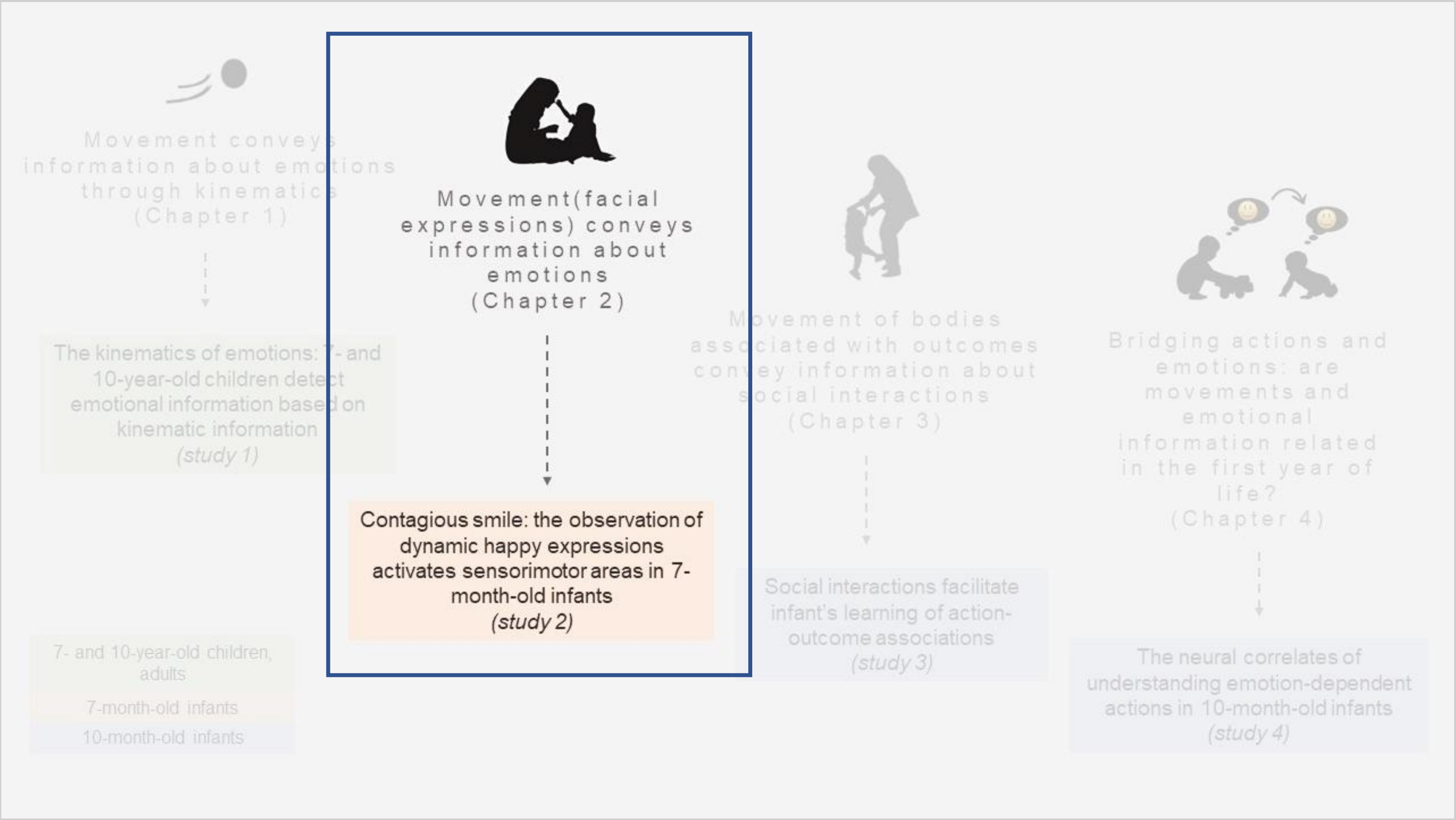
Chapter 2. Movement of facial expressions conveys information about emotions.



Contagious smile: the observation of dynamic happy expressions activates sensorimotor areas in 7-month-old infants[2] *(Study 2).*

Ever since birth, we are inclined to communicate with others through facial expressions (Rosenstein & Oster, 1988) and we are attuned to others' emotional displays (Addabbo, Longhi, Marchis, Tagliabue, & Turati, 2018). The recognition of emotions from others' facial expressions is truly fundamental for successfully managing multifaceted social interactions (Adolphs, 2002a). Perception and interpretation of others' faces play a crucial role in human communication, in learning about the social and physical world, regulating our emotions and developing relationships with others. This is especially true early in life, when infants cannot rely on language to understand others' behaviors, but mainly observe and interpret gestures and facial expressions to grasp others' intentions and feelings (Leppanen & Nelson, 2009; Leppanen, 2011). In the last decade, considerable efforts have been devoted to elucidating the neural underpinnings of the early development of emotion processing (e.g., Crespo-Llado, Vanderwert, Roberti, & Geangu, 2018; Jessen & Grossmann, 2015; Adolphs, 2002b).

Indeed, a substantial amount of brain imaging studies indicated the existence of a complex network of brain structures involved in the processing of facial emotional expressions in adults (e.g., Haxby, Hoffman, & Gobbini, 2000). This network includes cortical areas, such as the extrastriate regions of the occipital cortex, the fusiform gyrus and the superior temporal sulcus, as well as subcortical structures, such as the amygdala and insula (Eimer & Holmes, 2007). Consequently, a fundamental question regards how neural networks underlying the processing of emotional expressions are organized and how they might change during development. Given that facial expressions contain both emotional and motor components, several studies showed the involvement of the premotor and parietal cortex in facial expression observation and execution (Dapretto et al., 2006; van der Gaag, Minderaa, & Keysers, 2007). Nonetheless, little is still known about the role of sensorimotor areas in the processing of facial expressions during infancy.

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[2] Parts of this chapter are included in Quadrelli, E., Roberti, E., Polver, S., Bulf, H., Turati, C. (*In prep.*) EEG mu rhythm and network connectivity to emotional faces in 7-month-old infants.

Neurophysiological evidence for the recruitment of motor brain areas in response to emotion perception derives from the discovery of mirror neurons in the premotor and parietal cortices of monkeys (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992). Mirror neurons are a class of sensorimotor neurons originally studied in relation to the domain of actions and intentions (Fadiga, & Craighero, 2004; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Their function was later associated also with social processes, such as empathy and the processing of facial emotional expressions (Enticott, Johnston, Herring, Hoy, & Fitzgerald, 2008; Gallese, 2003; Kaplan, & Iacoboni, 2006). According to some authors, the recruitment of areas known to be involved in perceptual-motor coupling mechanisms speaks in favor of the hypothesis that facial expressions are recognized via a simulation mechanism (e.g., Bastiaansen, Thioux, & Keysers, 2009). Observing someone’s emotional expression directly generates motor and somatosensory activation in the observer as if he/she is feeling a similar emotional state (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003). Studies using a variety of techniques have shown that adults recruit specific sections of the premotor, parietal and sensory cortices during both observation and imitation of the main facial emotional expressions (Carr et al., 2003; Leslie, Johnson-Frey & Grafton, 2004; Pohl, Anders, Schulte-Ruther, Mathiak, & Kircher, 2013). For instance, a recent functional magnetic resonance imaging (fMRI) study (Williams et al., 2020) had the aim to explore whether and how different emotions specifically activate the mirror neuron system in facial emotion processing. Participants, other than watching short video clips of dynamic happy, angry, non-emotional (lip-protrusion), and neutral (no movement) facial expressions, were asked to produce the same facial expressions themselves. Results revealed emotion-specific activation for production and perception of the positive (happy) and a negative (angry) emotional expression compared to the neutral facial expressions. Interestingly, the difference between activations for the two emotions (i.e., activation in the right temporal pole for happy facial expressions and in the left inferior frontal gyrus, pars orbitalis, and the cerebellum for angry facial expressions) were better observed when the non-emotional facial expression condition was filtered out of the images. This confirms that, in general, the movement intrinsic in emotional expressions plays an important part in brain activation. To date, most studies on the neural correlates of emotion processing in the first years of life assessed infants' attention allocation and perceptual discrimination abilities in response to facial expressions (e.g., Peltola, Leppanen, Maki, & Hietanen, 2009; Quadrelli, Conte, Macchi Cassia, & Turati, 2019; Taylor-Colls, & Fearon, 2015). These studies, using electroencephalography (EEG), consistently demonstrated that heightened sensitivity to happy faces persists until 7 months, when infants' attention allocation is more pronounced in response to happy than to negative facial expressions (Peltola et al., 2009; Taylor-Colls, & Fearon, 2015). Between 7 and 12 months of age, infants' attention starts to be preferentially attracted respectively by fearful and angry faces when these are contrasted to happy faces (Grossmann, Striano, & Friederici, 2007), giving rise to an attentional bias towards negative expressions. This transition in attention allocation resources across the first year of life is thought to derive from an experience driven process. The early bias towards positive emotional expressions has been interpreted as resulting from infants' extensive exposure to positive interactions with primary caregivers and other adults (Vaish, Grossmann, & Woodward, 2008). The negativity bias typically emerges when improved motor skills (e.g., crawling and fine grasping) and the risk of harm that they pose increase the occurrence of fearful and angry expressions within the infant's environment (Leppanen, 2011). Recent research also suggests that infants are sensitive to facial dynamics, which may affect their processing of emotional expressions (Addabbo et al., 2018; Missana, Grigutsch, & Grossmann, 2014; Rotem-Kohavi et al., 2017), as well as infants' attentional biases toward emotional signals (Quadrelli et al., 2019).

The above-mentioned literature focused on the neural correlates of attentional or perceptual processing of emotional expressions, without taking into account the role of sensorimotor processing across the first years of life. Yet, this is a particularly important time window in the development of emotion comprehension, both in terms of familiarization with others' displays and with first person motor experience (Rennels & Davis, 2008).

Recent studies collecting surface electromyography (sEMG) data from a wide range of age groups reported that observing facial gestures or emotional expressions elicits specific muscular activation patterns (e.g., Datyner, Henry, & Richmond, 2017; de Klerk, Bulgarelli, Hamilton, & Southgate, 2019; Hashiya, Meng, Uto, & Tajiri, 2019). For example, it was shown that 3-year-old children exhibited increased zygomaticus major activity (i.e., the primary muscle involved in smiling) in response to happy faces, while angry faces generated an increased electromyographic (sEMG) activation of the frontalis muscle, which is typically involved in expressing fear (Geangu, Quadrelli, Conte, Croci, & Turati, 2016). Furthermore, when presented with happy, angry, and fearful facial expressions, 4-month-olds did not display selective sEMG activation of the facial muscles. On the other hand, 7-month-olds showed selective activation of the zygomaticus major and frontalis muscles respectively for happy and fearful expressions, while angry expressions did not elicit a specific response (Kaiser, Crespo-Llado, Turati, & Geangu, 2017).

An additional electrophysiological measure, which has been used to explore the motor and sensorimotor components of emotion processing, is mu (µ) rhythm suppression, or desynchronization. This measure is typically found at central scalp locations within the alpha frequency band (i.e., 6-9 Hz in infants) (Marshall, Bar-Haim, & Fox, 2002). Mu rhythm suppression is considered as an index of activity linked to perceptual-motor coupling mechanisms, being generated in the sensorimotor cortex during both action execution and perception (e.g., de Klerk, Johnson, & Southgate, 2015; Fox et al., 2016; Quadrelli, Geangu, & Turati, 2019b). More recently, mu suppression in response to facial emotional expressions was also explored in the first years of life. Rayson and colleagues (2016) recorded thirty-month-olds' sensorimotor activation during observation of dynamic emotional (i.e., sadness and happiness) and non-emotional facial expressions (i.e., mouth opening). They showed that µ desynchronization occurred bilaterally in central clusters during observation of non-emotional mouth opening expressions, while it was found only in the right hemisphere during observation of happy and sad facial expressions (Rayson, Bonaiuto, Ferrari, & Murray, 2016). The same authors recorded similar results also in 9-month-old infants. Specifically, they found significant mu desynchronization in response to the observation of happy, sad and mouth opening facial expressions compared to scrambled faces over the right hemisphere (Rayson, Bonaiuto, Ferrari, & Murray, 2017). Nonetheless, these results do not clarify whether sensorimotor activation at 9 months is specifically elicited by emotional expressions or if it is determined by the observation of faces or face movements in general. Indeed, empirical evidence indicates that, among negative emotions, recognition of sadness is characterized by a longer developmental trajectory compared to the recognition of fear and anger (Izard, 2007). Thus, the fact that a similar response has been observed for a highly familiar emotional expression (i.e., happiness), a non-emotional expression (i.e., mouth opening) and an emotional expression (i.e., sadness) that is known to be recognized only later in development, seems to question the possibility that sensorimotor activation is specifically elicited by facial expressions of emotions in infancy.

The current study addresses this issue by investigating 7-month-old infants' sensorimotor response to static and dynamic facial expressions of happiness and anger. The choice of this age group was due to the abovementioned shift from a heightened sensitivity to happy faces (Peltola et al., 2009; Taylor-Colls, & Fearon, 2015) to fearful and angry faces (Grossmann, Striano, & Friederici, 2007). We hypothesized that the observation of a significant µ rhythm desynchronization when both emotional expressions are posed by dynamic but not static faces would strengthen the idea that sensorimotor areas are activated in response to any facial movement. On the other hand, the observation of a differential pattern of activation determined by the emotional valence of the stimuli would indicate a specific sensorimotor activation for the emotional expressions. In particular, we predicted a greater activation generated by happy compared to angry expressions in the dynamic condition, as happiness- is more extensively experienced and elicits an early attentional bias in the first months of life (e.g., Vaish et al., 2008). In a previous study, Quadrelli and colleagues (2019) investigated a similar question using event-related potentials (ERPs). They found that happy faces evoked a faster right-lateralized negative central (Nc) component compared to angry faces. Furthermore, both happy and angry faces elicited a larger right-lateralized Nc compared to neutral faces. Since the age group of interest was the same, and both paradigms involved the use of static and dynamic facial expressions, we decided to use the dataset previously collected. The methods described below will therefore be the same as described in Quadrelli et al., 2019. In the present study, we did not include the neutral condition in the analyses, given that the previous analyses suggested that infants' neural sensitivity to emotional expressions was greater.

Methods

Participants

Thirty-eight 7-month-old infants (20 males, M age = 217 days, SD = 13 days, range = 201-233 days) were included in the final sample. Infants were randomly assigned to one of two experimental conditions, so that 19 infants were presented with the dynamic condition, and 19 infants were presented with the static condition. All infants were recruited from a diverse urban environment including the metropolitan and suburban areas of Milano (Italy), were born at term (37-42 weeks gestation), had a normal birth weight (>2500 g), did not suffer of any neurological or other medical conditions, and had normal vision and hearing for their age. An additional 22 infants were tested but excluded from final analysis due to fussiness (n= 8), excessive artifacts (n=12), or technical problems with data collection (n=2). The sample size and proportion of excluded infants is similar to other EEG studies investigating µ rhythm with infants this age (e.g., Gerson, Bekkering, & Hunnius, 2015; Paulus, Hunnius, van Elk, & Bekkering, 2012). The procedure followed the ethical standards (the Declaration of Helsinki, BMJ 1991; 302:1194) and was approved by the ethical committee of the University of Milano - Bicocca (Protocol number: 236). Participants were recruited via a written invitation that was sent to parents based on birth record provided by neighboring cities. The study was explained to the parents and their written consent was obtained.

Stimuli

Stimuli in the dynamic condition consisted of short 1000 ms color videos of 6 female Caucasian actresses posing angry and happy facial expressions while facing forward. All videos were extracted from the Binghampton University 4D Facial Expression database (BU-4DFE; Yin, Chen, Sun, Worm & Reale, 2008). The unfolding of each emotional expression (i.e., neutral to 100% intensity) lasted 500 ms, and the full expression remained on the screen until the end of the video (i.e., for another 500 ms). In the static condition, all stimuli consisted of photographs depicting the full emotional expression (100%) extracted from videos used in the dynamic condition and presented for 1000 ms. There was no overlap between the identities posing the two facial expressions as a different identity was used for each emotion. Using the software Adobe Photoshop, all the stimuli were cropped into an oval shape to remove hair and external features in order to emphasize and facilitate the processing of featural (i.e., features' shape) and configural (i.e., spatial distance and relation among the features) cues diagnostic of each emotion (Leitzke & Pollak, 2016; Richoz, Lao, Pascalis, & Caldara, 2018). Indeed, it is known that the external facial features greatly attract infants' attention (e.g., Leitzke & Pollak, 2016), and that masking the hair encourages the processing of the internal portion of the face (e.g., Mondloch, Geldart, Maurer, & Le Grand, 2003). All faces subtended 15.3° of visual angle vertically and 10.5° of visual angle horizontally when watched from approximately 60 cm and were pasted on a grey background. All stimuli were screened and selected for their emotional valence by asking 19 adult raters (13 females) to complete a survey in which they had to identify each emotion by choosing from the list of the six basic emotional expressions. They were also requested to assign to the face a score ranging from -10 (i.e., angry) to 10 (i.e., happy) to describe the intensity of the expressed emotion, with 0 corresponding to absence of emotional expression. In the static condition, happy and angry expressions were correctly identified by respectively 100% and 86% of the raters, while in the dynamic condition they were correctly identified by respectively 97% and 91% of the raters. Wilcoxon Signed-ranks tests performed for each emotion on the intensity scores indicated that in both the dynamic and static condition, happy (Dynamic: M = 7.16; SD = 0.84, Static: M = 7.20; SD = 0.81), Z > 3.83; *p*s < .001, η_p^2 > 1.63, and angry expressions (Dynamic: M = -6.89; SD = 1.31, Static: M = -6.56; SD = 1.08), Z > -3.84; *p*s < .001, η_p^2 > 1.63, were perceived as different from zero. All stimuli were also equalized for luminance, which did not differ between emotional expressions both in the dynamic (Mann-Whitney *U* = 3.00, *p* = .53) and static (Mann-Whitney *U* = 3.00, *p* = .51) conditions. Moreover, a comparison between the overall amount of motion displayed in the videos depicting the two dynamic facial expressions did not reveal any difference in the amount of motion between happy and angry expressions (Mann-Whitney *U* = 4.00, *p* = .83). The analysis of the motion content of the stimuli was performed through an established procedure described in Grossmann and Jessen (2017; see also Pichon, de Gelder, & Grèzes, 2009).

Procedure

The experiment took place in a dimly lit, audiometric and electrically shielded cabin, where participants were seated on their mother's lap, at approximately 60 cm from a 24-inch monitor, in a behavioral state of quiet alertness. Stimuli were presented using E-Prime software v2.0 (Psychology Software Tools Inc., Pittsburgh, PA). Mothers were instructed to remain as still as possible and keep silence during the experimental session in order to avoid any acoustic interference. The whole experiment was recorded through an infrared video camera, hidden over the monitor, which fed into the data acquisition computer, located outside the testing cabin. The data acquisition computer displayed the live image of the infants' face and body to allow the experimenter to pause or terminate the session when the infant became too fussy. Each infant was presented with all six face identities, either in a dynamic or static condition, which were presented in a random order, with the only constraint that models expressing the same emotion could not occur more than three times in a row. The experimental session was terminated when infants attended to the maximum number of trials (N = 180) or got tired of the experiment. A trial consisted of 1000 ms stimulus presentation followed by an inter-stimulus interval, which varied randomly between 900 and 1100 ms. After this, another trial was presented (Figure 1). Whenever necessary the experimenter presented a looming fixation point between trials to reorient the infant's attention to the monitor. The caregivers were instructed to keep their child attention to the screen ahead without distracting them by pointing or vocalizing.

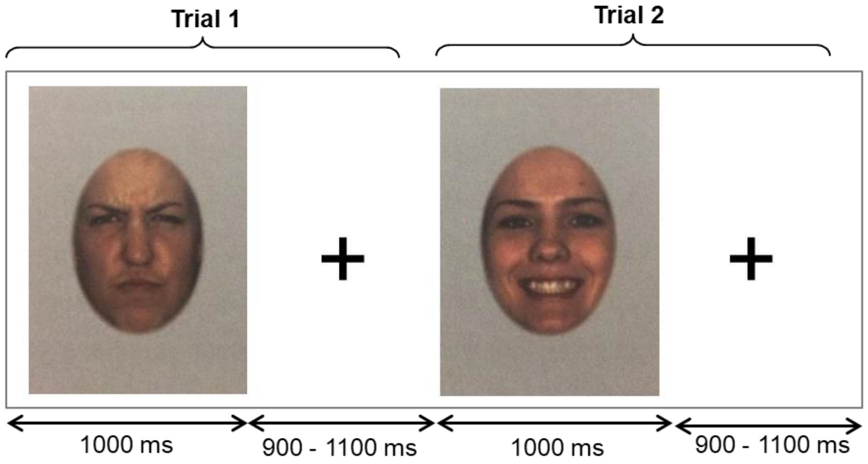

Figure 1. Example of two consecutive trials, in which an angry and a happy facial display were presented. Each infant saw six different randomized identities, either in a dynamic or static condition. The experimental session was terminated when infants attended to the maximum number of trials (N = 180) or got tired of the experiment.

EEG recordings

EEG was recorded using a 128-electrode HydroCel Geodesic Sensor Net (Electrical Geodesic In., Eugene, OR) and sampled at 500 Hz by means of an EGI NetAmps 300 amplifier. The signal was recorded with respect to the vertex electrode and re-referenced to the average reference. A bandpass filter of .1 to 100 Hz was applied online, and impedances were checked prior to the beginning of each session and considered acceptable if lower than 50 KΩ. EEG data were further high-pass filtered offline (0.3 Hz) and segmented into 2400 ms segments, beginning 1000 ms before and ending 1400 ms after stimulus onset.

EEG data was pre-processed using Netstation v4.6.4 and analyzed using WTools (Parise & Csibra, 2013). For eliminating artifacts, segmented data were automatically rejected whenever the signal exceeded ± 200 μV at any electrode. Further visual inspection of the video recorded throughout the experiment checked for any trials in which the infant did not attend to the screen or made any gross or fine limb or head movements in order to subsequently exclude those trials in which eye-movements, eye-blinks and any other body movement artifacts not detected by the automated algorithm. Trials were excluded if more than eighteen (i.e., 15%) bad channels were detected. Of the remaining trials, individual bad channels were replaced using spherical spline interpolation. Only infants with at least 5 artifact-free trials per condition were included in the analyses (Cannon et al., 2016). The mean number of artifact-free trials contributing to analyses was 7.39 (happiness: 7.53, SD = 2.12; anger: 7.26, SD = 2.74) in the dynamic condition, and 7.92 (happiness: 8.26, SD = 2.46; anger: 7.58, SD = 2.20) in the static condition. There were no significant differences between the two conditions and emotions in the number of artifact-free trials (all *p*s > .07). Time-frequency analyses were performed on each artifact-free trial using continuous wavelet transform with Morelet wavelets at 1 Hz intervals in the 3 to 20 Hz range. After similar studies investigating µ rhythm desynchronization (e.g., de Klerk, Johnson, Heyes, & Southgate, 2015; Pomiechowska, & Csibra, 2017; Quadrelli, Geangu, & Turati, 2019b) or performing time-frequency analysis to uncover other stimulus-induced oscillatory responses in infancy (e.g., Csibra, Davis, Spratling, & Johnson, 2000; Parise, & Csibra, 2013), we calculated the absolute value (i.e., the amplitude, not the power) of the resulting complex coefficients. To eliminate distortion created by the wavelet transform, the first and the last 400 ms of each epoch were removed and a 500 ms baseline period starting 600 ms before stimulus onset was selected. Based on previous work showing that in infants of this age, the frequency band most reactive to movement is the 6-9 Hz band (Marshall & Meltzoff, 2011; Marshall, Bar-Haim, & Fox, 2002), we averaged activity over this range. Averaged activity in the 6-9 Hz range during the 500 ms baseline was then subtracted from averaged activity recorded during stimulus presentation. Average wavelet coefficients within infants were calculated by taking the mean across the trials. As in previous studies investigating sensorimotor activation in response to emotional expressions in infancy (Rayson et al., 2017; 2016), activity over a cluster of electrodes disposed over the left-hemisphere (29, 30, 31, 36, 37, 41 and 42), the right-hemisphere (79, 80, 86, 87, 93, 103, 104, and 105) were analyzed. The scalp locations of these left and right lateral electrode clusters correspond to the locations of C3 and C4 in the international 10–20 system of electrode placement (Figure 2). The average activity in the 6-9 Hz range was extracted for statistical analyses from these two regions in the 400-800 ms time window. This time window was chosen based on visual inspection of the data, indicating that activation elicited by the employed emotional expressions reached its peak across participants within this time window. All individual averages were also visually inspected to ensure the chosen time window was appropriate. In addition, because we wanted to know whether sensorimotor suppression while infants observed the emotional expressions was specific to the central region or extended to the occipital region (Cuevas, Cannon, Yoo, & Fox, 2014), we also analyzed the channels over the occipital cortex (70, 71, 75, 76, 83), corresponding to O1/Oz/O2 according to the international 10–20 system of electrode placement. All statistical tests were conducted on a .05 level of significance (two-tailed). Normality of the data was checked: statistical tests performed revealed that all variables were distributed normally (Shapiro-Wilk *p*>0.05). When the ANOVAs yielded significant effects, pairwise comparisons including ≤ 3 means were performed by applying t tests and the Fisher's least significant difference procedure (Howell, 2012), and Holm-Bonferroni correction was used where appropriate (Abdi, 2010).

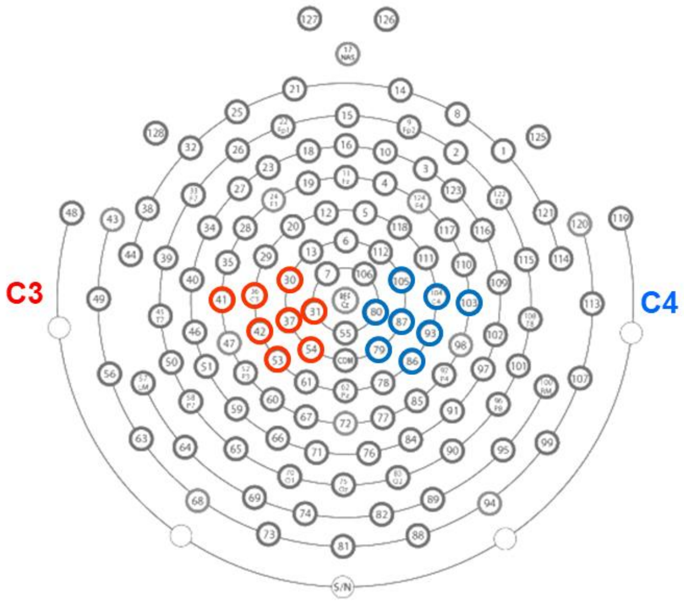

Figure 2. Selected electrode clusters covering the left (C3 – 29, 30, 31, 36, 37, 41 and 42) and right (C4 – 79, 80, 86, 87, 93, 103, 104, and 105) scalp locations.

Results

We compared the scalp distribution of sensorimotor alpha suppression over central electrode sites during the observation of dynamic and static happy and angry facial expressions in 7-month-old infants. To do so, we used a 2 x 2 x 2 repeated measures analysis of variance

(ANOVA) with experimental condition (dynamic, static) as between-subject factor, and electrode cluster (C3, C4) and emotion (happiness, anger) as within-subject factors.

The ANOVA yielded a significant main effect of emotion, *F* (1,36) = 9.41; $p < 0.01$, η_p^2 = 0.21, with happy expressions (*M* = -0.14 µV; *SD* = 0.35 µV) eliciting greater sensorimotor alpha suppression compared to angry faces (*M* = 0.004 µV; *SD* = 0.35 µV) irrespectively of the experimental condition. However, the main effect was qualified by a significant emotion by electrode cluster interaction, *F* (1,36) = 8.72; $p < .01$, η_p^2 = .19. Post-hoc comparisons showed that there was more sensorimotor alpha suppression for happy (*M* = -0.21 µV; *SD* = 0.35 µV) compared to angry expressions (*M* = 0.06 µV; *SD* = 0.39 µV) over C4 (i.e., right hemisphere), *t* (37) = 4.08; $p < .001$, *d* = 0.66. All other comparisons did not reach statistical significance (all $p > 0.12$). Furthermore, a significant emotion by experimental condition interaction, *F* (1,36) = 6.32; $p = 0.02$, η_p^2 = 0.15, was also found. Thus, in order to disentangle this interaction, post-hoc comparisons were conducted separately for each experimental condition. The analysis of the dynamic experimental condition revealed that happy facial expressions (*M* = -0.28 µV; *SD* = 0.29) elicited more sensorimotor alpha suppression compared to angry faces (*M* = -0.02 µV; *SD* = 0.39), *t* (18) = -4.11; $p < 0.001$, *d* = .94 (Figure 3). Conversely, the analysis of the static experimental condition did not reveal a significant difference between happy (*M* = 0.00 µV; *SD* = 0.35) and angry (*M* = 0.03 µV; *SD* = 0.32) emotional expressions, *t* (18) = -0.38; $p = .71$, *d* = 0.08.

Additionally, one sample t-tests were performed to investigate the magnitude of sensorimotor alpha suppression as compared to baseline in both experimental conditions and both electrode clusters in response to happy and angry facial expressions. In the dynamic experimental condition, sensorimotor alpha suppression in response to happy expressions over the C4 electrode cluster (*M* = -0.38 µV; *SD* = 0.27) was significantly different from zero, *t* (18) = -6.23; $p < 0.001$, *d* = 1.43. No other comparisons attained significance in the dynamic condition (all $p > 0.07$). In the static experimental condition, both facial expressions over the two electrode clusters failed to attain statistical significance (all $p > 0.58$). Finally, to determine whether sensorimotor alpha suppression was specific to central sites, similarly to previous studies (e.g., Cannon et al., 2014; Filippi et al., 2016; Southgate & Vernetti, 2014; Upshaw, Bernier, & Sommerville, 2016) we performed a separate repeated measures ANOVA with emotion (happiness, anger) as within-subject factor and experimental condition (dynamic, static) as between-subject factor on activation over occipital electrodes. The analysis of the occipital cluster (O1/Oz/O2) did not yield significant main or interaction effects (all $p > 0.15$). However, activation of occipital regions during the observation of emotional expressions in both experimental conditions was significantly different from baseline activation (static happiness: $M = -1.21$ µV, $SD = 1.20$; static anger: $M = -0.97$ µV, $SD = 1.04$; dynamic happiness: $M = -1.52$ µV, $SD = 1.27$; dynamic anger: $M = -1.21$ µV, $SD = 1.10$; all $p < 0.001$). Thus, while there was a modulation of sensorimotor suppression at central channels in response to the observed emotional expressions and the specific experimental conditions, over the occipital cluster all facial expressions in both experimental conditions elicited a significant activation as compared to baseline.

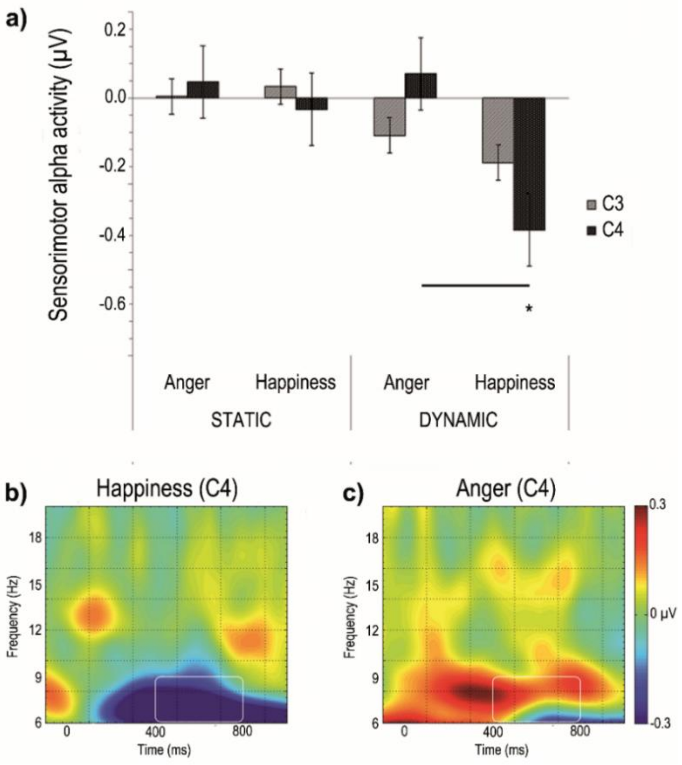

Figure 3. (a) Mean alpha activity over the selected electrode clusters covering the left (C3 – left hemisphere; grey bars) and right (C4 – right hemisphere; black bars) sensorimotor areas, during the observation of static and dynamic happy and angry facial expressions. Significant suppression from baseline and significant comparisons between conditions are illustrated, * p < .05. Error bars represent the standard errors of the means. In the bottom left **(b)** and right **(c)** panels, time-frequency plots display baseline corrected activity respectively for the dynamic happy and angry faces over the right sensorimotor area (i.e., C4).

Discussion

Studying the neural bases of the development of emotion perception can provide useful insights into the mechanisms by which the ability to interact with a social world develops. The motor and sensorimotor components of emotion processing in response to facial emotional expressions, as indexed by the mu rhythm suppression, been investigated both in adults (Enticott et al., 2008; Gallese, 2003; Carr et al., 2003; Leslie et al., 2004; Pohl et al., 2013) and in the first years of life (Rayson et al., 2016; Rayson et al., 2017). Nonetheless, compared to the adult literature, the infant studies are only beginning to scratch the surface on this matter.

For this reason, the present study investigated whether the observation of faces expressing different emotions in a dynamic compared to a static manner was able to generate activation of the sensorimotor cortex. In particular, we aimed to verify if angry and happy expressions were capable of eliciting sensorimotor activation in 7-month-old infants. Our results provide evidence of a differential modulation of μ rhythm desynchronization in response to static and dynamic emotional expressions at 7-months of age. Indeed, happy facial expressions elicited greater sensorimotor activation compared to angry faces in the dynamic experimental condition, while no difference was found between the two emotional expressions in the static condition, when sensorimotor activity did not differ also from baseline. This finding is in line with considerable evidence suggesting that dynamic information is beneficial for various aspects of face processing across the lifespan. Several studies demonstrated that dynamic facial expressions enhanced emotion recognition abilities (Ambadar, Schooler, & Cohn, 2005; Krumhuber, Kappas, & Manstead, 2013) and generated stronger emotion-specific mimicry responses in adults (Rymarczyk, Biele, Grabowska, & Majczynski, 2011; Weyers, Muhlberger, Hefele, & Pauli, 2006). Research showed that 5-month-olds presented with dynamic facial expressions displayed an attentional bias towards faces expressing negative emotions (Heck, Hock, White, Jubran, Bhatt, 2016; 2017), and that 7-month-old infants showed a differential modulation of event-related potential responses to dynamic vs static emotional faces (Quadrelli et al., 2019a). Adding to this body of evidence, the current results further suggest that the perception of dynamic compared to static emotional faces increases sensorimotor activation to happy compared to angry faces. Dynamic facial expressions are more similar to those that occur in everyday life, and they constitute a powerful means for emotional communication compared to static expressions.

The differential activation pattern elicited by happy and angry faces in the dynamic condition further extends evidence of sensorimotor sensitivity to emotional expressions in infancy. It is possible to hypothesize that activation of sensorimotor areas to happy faces might be more specialized compared to negative emotional expressions in the first months of life. Indeed, the interplay between infants' spontaneous preference for happy facial expressions (Farroni, Menon, Rigato, & Johnson, 2007) and the greater experience accumulated with expressions of happiness compared to angry faces early in life (Hoehl, 2014; Vaish et al., 2008), might lead to a facilitation in sensorimotor activation for positive emotions. On the other hand, the experience with anger is intuitively smaller in the first 7 months of life, and this is responsible for an insufficient contingency learning for this specific emotion (Sullivan, 2018). According to the neuroconstructivist perspective, observation and active experience would be responsible for the gradual specialization of perceptual-motor couplings (Quadrelli & Turati, 2015) and, as recently outlined, infants' early experience with faces might lead to a rapid attunement of face-sensitive cortical structures to the more experienced facial expressions (Leppanen & Nelson, 2009).

Notably, activation elicited by happy faces over the right hemisphere in the dynamic experimental condition was the only case in which µ rhythm suppression attained significance as compared to baseline. This right hemisphere dominance is consistent with evidence from existing studies on sensorimotor activation to emotional expressions in toddlerhood (Rayson et al., 2016) and adults (e.g., Moore, Gorodnitsky, & Pineda, 2012). Indeed, this activation pattern extends evidence highlighting the prominent role of the right hemisphere in the processing of emotional information from faces (Calvo & Beltran, 2014). Interestingly, it appears from current results that the lateralization of the neural response to faces with positive emotional value does not imply a prolonged developmental trajectory. Rather, these data support the idea that the dominance of the right hemisphere for processing happy expressions is present very early in life. However, differently from previous studies with older infants and toddlers (Rayson et al., 2016; 2017), 7-

month-olds did not show a significant activation in response to negative expressions over the right hemisphere. The absence of activation in response to angry faces, together with the specific response to happy expressions, fosters the abovementioned idea that perceptual and motor experience with smiling in the first months of life lead to the maturation of a specialized sensorimotor activity for the processing of (Leppanen & Nelson, 2009) that still lacks for angry expressions.

The absence of significant sensorimotor activation in response to angry faces in the dynamic condition is in line with previous investigations exploring spontaneous facial reactions to angry emotional expressions in infancy and early childhood (Geangu et al., 2016; Kaiser et al., 2017). It is likely that this result is at least partially due to the insufficiently developed ability of 7-month-old infants to extract the emotional value of angry facial expressions. Moreover, differences in exposure to angry compared to happy expressions may be responsible for a longer time course in the emergence of sensorimotor activation in response to angry facial expressions.

Happy and angry static facial expressions did not elicit a significant modulation compared to baseline and did not show a differential sensorimotor activation pattern in 7-month-old infants. Results from previous studies employing static stimuli demonstrated that observation of happy faces generated greater μ rhythm suppression compared to expressions of disgust in adults (e.g., Moore et al., 2012), and that 7-month-olds exhibited greater zygomaticus activation in response to the observation of happy compared to angry static expressions (Datyner et al., 2017).

The lack of neural differentiation between happy and angry static faces in our study might be due to methodological aspects. First, it is possible that infants in our study were not able to fully encode happy and angry facial expressions in the static condition since the stimuli were presented very briefly (i.e., 1 second) compared to the static faces employed in the previous sEMG study (i.e., 5 seconds) (Datyner et al., 2017). Thus, it is plausible that the absence of dynamic and more ecologically valid information together with the shorter stimulus duration may have a detrimental impact on the observed activation pattern in the static condition. Secondly, we included participants with the minimum requirement of 7 trials per condition. This might have decreased the possibility to observed subtle differences between happy and angry static faces. The availability of more trials might have strengthened our results. Nonetheless, this criterion is common in the literature when complex electrophysiological paradigms are employed with infant participants (Bristow et al., 2008; Geangu, Roberti & Turati, 2021; Hoehl & Wahl, 2012). Thirdly, if the effects are distributed unevenly over the ROI, the hypotheses driven selection of the clusters might not capture all significant effects. An approach that could enhance the ability to identify statistically significant patterns is the *Permutation Statistics for Connectivity Analysis* (Mamashli, Hämäläinen, Ahveninen, Kenet & Khan, 2019), which could be taken into consideration in further statistical analyses on our data and future studies on this topic.

Importantly, no differences were highlighted across conditions and emotional expressions over the occipital cluster. Conversely, as previously noted, µ rhythm desynchronization was modulated differently both as a function of the dynamic vs static experimental condition and the emotional expressions over the central electrode clusters. No significant differences in occipital alpha activity emerged between emotional expressions. However, our results also highlight the presence of significant alpha activity in all conditions and emotions as compared to baseline. These findings are consistent with previous reports showing that in infants (Filippi et al., 2016) and in adults (Marshall, Bouquet, Shipley, & Young, 2009), µ rhythm suppression over central regions is accompanied by alpha desynchronization recorded from occipital electrode clusters. Occipital alpha is known to be linked to visual attention (Warreyn et al., 2013; Debnath, Salo, Buzzell, Yoo, & Fox, 2019). The occipital alpha attenuation we have found regardless of the observed condition and emotional expression might therefore reflect the involvement of an attentional component during the observation of salient stimuli, such as static or dynamic emotional expressions of happiness or anger.

Taken together, results from the current study provide evidence of a modulation of sensorimotor activity in response to dynamic emotional expressions as early as 7 months of age. Additionally, our findings speak in favor of the existence of a right-lateralized sensorimotor activation in response to dynamic expressions of happiness, consistent with the hypothesis of an early specialized right-hemisphere dominance for the processing of more experienced happy facial expressions. As stated by Williams and colleagues (2020), it is important to consider that emotion understanding is based on several distinct, although related, processes. Therefore, addressing the relevance of the sensorimotor system is a piece of the puzzle that surely is interesting, but will need to be included in integrative models (Spunt & Adolphs, 2017). According to this idea, a functional connectivity analysis might be beneficial for the present study. Some studies suggest that attentional processes and mirroring are mediated by a common functional network (specifically in occipital and central regions) and a shared oscillatory frequency (mu/alpha) (Bowman et al., 2016; Cannon et al., 2016; Yoo et al., 2016). Providing evidence for simultaneous, but distinct and correlated activity (i.e., occipital alpha and central mu) would support the use of mu rhythm suppression as an index of mirroring activity (Debnath et al., 2019). Finally, adding a condition in which infants produce the emotional displays themselves, as done by Rayson and colleagues (2017) would be interesting to see how the recruited networks overlap. In that study though, authors collapsed across condition (i.e., happy, sad, mouth opening) for the execution analysis due to small numbers of available expressions. We therefore believe that a similar analysis would be truly informative in a bigger sample, where the distinction at least between the positive and negative expressions would be possible.

This study involved 7-month-infants and the observation of static and dynamic facial expressions. The movement conveyed through facial muscles while emotional expressions are unfolding is not the only relevant one in social settings. Indeed, even emotionally neutral movements inscribed in a multi-personal and multi-modal environment can become a communication tool. This kind of interaction will be the focus of investigation in the study presented in the next chapter: emotional displays will be referenced to a situation in which a novel object is presented. We will investigate how infants, before the year of age, expect people to interact with such objects and whether they use emotional displays to form such expectations.

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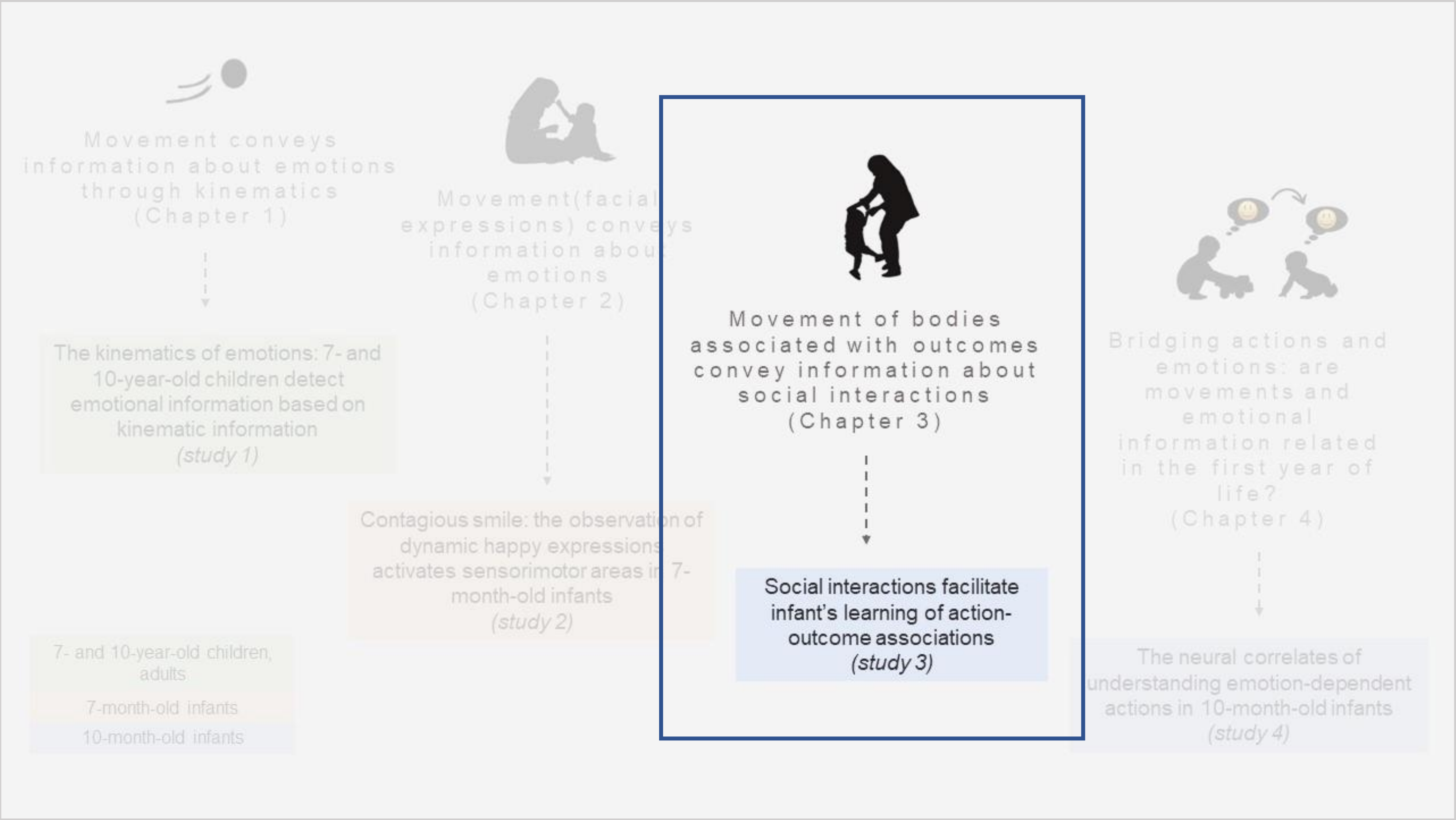
Chapter 3. Movements of bodies associated with outcomes conveys information about social interactions.



Social interactions facilitate infants' learning of action-outcome associations (Study 3)[3]*.*

Through our own body, we are able to communicate. By looking at someone, by a movement of a hand or the head, by walking towards or away from someone, we can express a multitude of meanings. Understanding other people's interactive scripts (e.g., give-and-take interactions) is essential for successfully navigating the social world, as not only it allows the comprehension of others, but it also enable to take part in such interactions (Gredeback & Melinder, 2010). Infants engage in collaborative activities since very early on in life. Discriminating how others act is therefore extremely relevant: without an understanding of others' actions, their everyday interactions would be compromised (Henderson, Wang, Matz & Woodward, 2013). In the following paragraphs, we will first delineate the state of art of the literature dedicated to the development of infants' capacity to understand goal directed actions and social interactions. Then, we will briefly make reference to the literature addressing infants' capacity to understand the spatial-temporal causality between events. In particular, one interesting observation that emerged from this literature is that 10-month-olds are not able to create associations between action and sound outcomes when actions strictly concern objects (Perone & Oakes, 2006). Given the importance of bodies on learning interactive rules, we designed a study to test the hypothesis that the action-sound associations would be perceived as salient, and therefore more easily encoded, if expressed through bodies rather than objects.

Within the first year of life infants learn to anticipate other people's behavior and plan their own actions accordingly (Sebanz, Bekkering & Knoblich, 2006; Striano & Stahl, 2005). One of the first goal-directed actions that infants actively experiment is feeding between 4- and 6-months of life, along with grasping objects with the goal of moving them or exploring them (Falck-Ytter, Gredebäck & von Hofsten, 2006). Infants master this second action only around 9 months of life,

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[3] Parts of this chapter are included in Sacheli, L. M., Roberti, E., Turati, C. (*In prep.*) Social interactions facilitate infants' learning of action-outcome associations.

although they start practicing it at around 4-5 months (McCarty & Keen, 2005). Some studies showed that already 4-month-olds manifest anticipatory gaze towards the goal of a grasping action (Geangu, Senna, Croci & Turati, 2015), and 6-month-old infants foresee the goal of an action when this consists in an actor moving a spoon towards her mouth, while this anticipation is lacking when the spoon is self-propelled (Kochukhova & Gredebäck, 2010). Infants' understanding of goals is not limited to actions performed on objects or on one's own body but can also be extended to cooperative settings where more partners are involved. For instance, Henderson and colleagues (2013) showed that 10-month-olds, when provided with direct experience of a collaborative setting (i.e., experimenter and infants completed a collaborative task, with the aim of retrieving a ball from a box), interpret later observed individual actions of adults as directed towards the same goal. This emphasizes the important role that active experience plays in infants' understanding of goal-directed action (e.g., Gerson & Woodward, 2012; Sommerville, Woodward & Needham 2005; Woodward, Sommerville, Gerson, Henderson, & Buresh, 2009). A direct experience of collaborative settings facilitates individual actions' interpretation as cooperative (Henderson et al., 2013). One question that remains open is whether the actions-effects associations are formed based solely on active experience with such associations, or if the shared nature of interactions helps towards creating predictions based on social features. A better understanding of how social interactions and joint attention are of foremost relevance in the development will help us shed a light on this matter.

Anticipating other people's behavior is a key element in planning one's own actions and in reacting to a partner's action on the context of social interactions, i.e., Joint Actions (Sebanz, Bekkering & Knoblich, 2006; Sacheli et al., 2019). Infants between 3 and 9 months of life are sensitive to joint attention cues, as shown by the fact that in social interactions they modify their behaviour according to the one of adults present in the same setting (Striano & Stahl, 2005). Social interactions are therefore fundamental from early on in development, contributing to the development of other skills such as joint attention, that are at the basis of imitation and language learning (Tomasello, 1995). Social interactions even influence object processing in 9-month-old infants, enhancing their active exploration (Striano, Chen, Cleveland & Bradshaw, 2006; Striano, Reid & Hoehl, 2006).

Infants, even in the early social interactions with their caregivers, learn that there is a structure to be respected, made of sequential responses between the partners (Dunham & Dunham, 1990). This structure is also known as turn taking and is essential in the development of later attachment and of cognitive domains such as the language one (Jaffe et al., 2001). In everyday interactions, rhythm does not necessarily mean following the same pattern. For instance, Jaffe and colleagues (2001) described it as "…a recurrent nonrandom temporal patterning that may or may not be strictly regular". Nonetheless, extracting regularities from such chaotic reality is fundamental for cognitive development. When two events or two people interacting synchronize themselves in a timely manner, the results is that the single events cohere into one (see Feldman, 2007 for a review on parent-infant synchrony and shared timing). Although a predisposition for contingency detection is already present at birth (Tarabulsy, Tessier, & Kappas, 1996; Jacquey, Fagard, Esseily & O'Regan, 2020), the comprehension of coordinated behaviors has been described as emerging later, specifically around 9 months of age (i.e., when social interactions mature and give-and-take mutuality starts being observed) (Stern, 1985; Feldman, 2007). This leads us to thinking that the observation of complex associations between actions and sounds, that was too complex to be encoded when the actions were performed on objects (Perone & Oakes, 2006, Perone et al., 2016), might be facilitated if it happens in an interactive context, more relevant and of extreme interest for infants after their 8 months of life. Between 8 and 12 months of age infants' awareness of people as intentional agents, that direct their actions towards specific goals, increases (Phillips, Wellman & Spelke, 2002). .

By the second year of age, infants can learn new cause-effect associations through a mechanism defined as *observational causal learning*, without the need of being part of the social interaction (Meltzoff, Waismeyer & Gopnik, 2012). Infants are capable to form categories of what they observe developing abstract, categorical representations based on spatial features or causal relations (Casasola & Cohen, 2002; Casasola & Park, 2013). Their spatial categorization abilities become more robust between 10 and 14 months of age (Casasola & Park, 2013). The development of such abilities has an underlying requirement: the understanding of spatio-temporal causality between events (Oakes & Cohen, 1990; Dündar-Coecke, Tolmie & Schlottmann, 2020). In particular, one feature that facilitates objects' categorization is their function. 10-month-old infants, habituated to an event that involved an object appearance and function (i.e., action and sound), learn the action or sounds association with an object. For instance, in the study by Perone and Oakes (2006), infants were capable to associate a single object, such as the spherical purple object with both the rolling *action* and the clicking *sound* produced by the action. On the other hand, they were not capable to attend to the correlation between the two dynamic features (i.e., rolling action and clicking sound). So, if an infant was habituated to two events involving the purple object, one that clicked when it was rolled and the other that whistled when it was pulled, in the test phase he/she may have been presented with the purple object that whistled when it was rolled (inverted features). In this scenario, infants did not increase their looking to these inverted test event, indexing that they did not learn cross-modal relations between the *actions* on objects and the resulting *sounds* (Perone & Oakes, 2006) (Figure 1). This might seem counterintuitive, since adults tend to learn object functions by creating a link between an action and its outcome (in this case the sound), but nonetheless it reveals that infants are learning object properties, although in a different way (Perone, Madole & Oakes, 2016). The difficulties in encoding action-sound outcome associations might be due to the complex features that need to be analyzed in novel objects, a skill that is acquired only in time. Social interactions, on the other hand, are relevant from early on. Our hypothesis is that their saliency might constitute a facilitating effect in infants' encoding actions-effects associations.

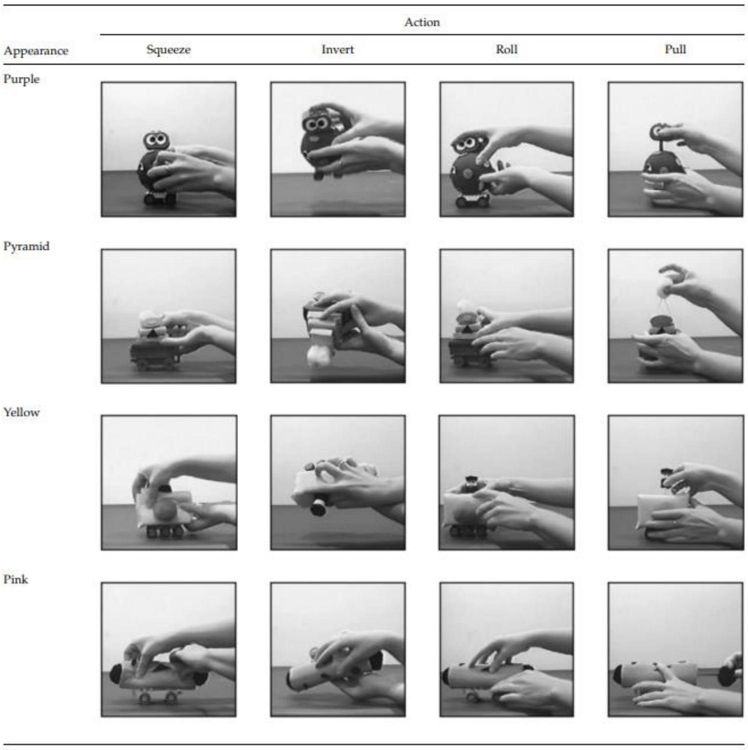

Figure 1. Example of objects and actions used in Perone & Oakes, 2006. Each video involved the manipulation of an object, obtaining different combinations of three features: object appearance (a spherical purple object; a cube-shaped yellow object; a pink tubular object; a pyramidal-shaped multicolored), an action on the object (rolling back-and-forth, squeezing the center, inverting the entire object, or pulling the part at the top or side of the object), and a sound produced by the action (clicking, mooing, squeaking, or whistling). When the object was acted on, a sound was produced that was temporally synchronous with the action.

Experimental study

Infants by the second year of age are able to learn new cause-effect associations in interactions (Meltzoff, Waismeyer & Gopnik, 2012). For instance, when they observe two adults play a novel social game (one adult shook a wooden object, and second adult as a response dispensed a marble) (Waismeyer & Meltzoff, 2017), the causal learning is not limited to physical outcomes, but they actively use their observations of a social interaction between two people to make decisions about their own future acts in the same social situation. Infants' observational causal learning is therefore not constrained to learning about *physical* outcomes, but rather, once people are involved and interact through communicative gestures, a set of factors beyond strict physical causal reasoning comes into play. This observation conveys towards the importance of investigating how younger infants encode social interactions and learn associations from them.

To sum up, infants actively acquire experience on action-outcome associations in terms of motor scripts, goal directedness, spatial relations and, more interestingly, also in terms of social and cooperative features. On the other hand, at 10 months of age they are not able to make the association of action and sound outcome when observed on objects. Given the relevance of the social world in the first year of age, our hypothesis was that the action-sound associations would also be perceived as salient, and therefore more easily encoded. The aim of the present study was therefore to investigate whether 10-month-old infants observing two actors, one performing an action and the other one responding with a vocalization, are successful in encoding such associations and therefore detect violations when such social scripts are disrupted.

Methods

Participants

The final sample consisted of twenty-one 10-month-old infants (mean age = 10 months and 14 days, *SD* = 8 days, 12 males). Participants were recruited in the area of the metropolitan city of Milano, Italy; they were born full term and did not have any history of neurological or significant medical condition, as reported by the parents on a questionnaire administered before the testing. Six additional infants were tested but excluded from the final sample because of technical problems (n=4), tests looking times above 2.5 standard deviations from the mean of the sample (*M*=19.3 s *SD*=11.4) (n=1), or incomplete procedure because of fussiness and lack of attention (n=1). Prior to the testing sessions, all parents were given information about the study and gave their written consent, according to the ethical standards of the Declaration of Helsinki (BMJ 1991; 302:1194 and later amendments). The ethics committee of the University of Milano - Bicocca approved the study.

Stimuli and design

The set of stimuli consisted of six videos lasting 1.5 seconds, in which two female actors stand in front of each other. One of the two actors performed an action directed towards the other person (i.e., delicately touching the forehead, the nose or the cheek), who responded emitting a vocalization (i.e., “Aah”, “Eeeh”, “Oh oh”) (see Figure 2 for some examples). In all recordings, the onset of the vocalization was set at two-thirds of the movement, specifically at the frame number 30 on a total of 45 frames per video. The vocalizations were pronounced by a woman, clearly and as attractive as possible for infants without having a particular emotional connotation.

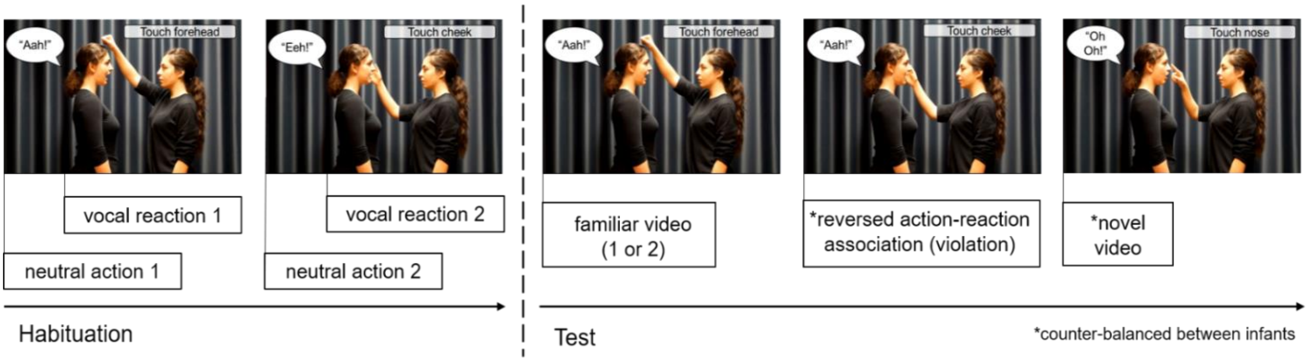

Figure 2. Example of a presentation. The number of trials for each habituation was determined by the infants’ online watching behavior: when habituation criterion was reached (i.e., average looking time of the last 3 consecutive trials decreased at least by 50% compared to the average looking time of the first 3 trials) the second video was presented. Whenever participants looked away for more than 2 seconds, another trial was presented. Between each trial an attention getter appeared and, when infants’ attention was regained, the following trial was started.

In a double habituation paradigm, infants were shown first a chosen action-sound pair (e.g., touching the forehead + sound “Aah”), looped until habituation criterion was reached. Then they were shown a second action-sound pair (e.g., touching the nose + sound “Eeh”), again until habituated. Three Test trials followed in the test phase: one of the familiar videos (Familiar Trial), an inverted action-sound association (in our example this would be, for instance, touching the nose + “Aah” sound) (Violation Trial) and a novel association (e.g., touching the cheek + “Oh Oh” sound) (Novel Trial). The familiar video presented was either the first or the second one the infants were habituated to, in a counterbalanced order between infants, and half of the infants saw the inverted video first, half of them saw the novel video first.

All the parents were also asked if their infants were able to perform actions similar to the ones observed and produced the vowels that they heard during the presentation, as this might enhance the ability to detect associated contingencies (Rochat & Striano, 2000; Jacquey et al., 2020). 100% of the infants were reported to produce the vowel “a”, 85.7% the vowel “e” and 61.9% the vowel “o”. As for the presented actions, 81% of the infants were reported to actively produce pointing, 95.2% the caress and 66.7% the closed fist movement. This confirmed that most infants had some sort of first-hand experience of what they observed, although with different frequencies.

Procedure

Participants sat on the caregiver’s lap, at a distance of approximately 60 cm from the screen, and the infant’s eye level was aligned to the center of the screen (24” screen size, 1920 x 1200 pixel resolution, 60 Hz refresh rate). The two actors, each 8 cm wide and 23 cm high, were facing each other at a distance of 5 cm, forming a visual angle of 21.7° vertically and 22.2° horizontally. An experimenter sat behind the monitor and recorded the looking time of the infant throughout the experiment. Once the infant looked at the monitor, the E-Prime 3 (*Psychology Software Tools*) script procedure was started. A trained experimenter who watched the live feed recorded each trial’s looking time (i.e., infants’ visual attention) by keeping the mouse pressed and releasing it when the participant looked away. When the look away lasted for more than 2 seconds, the program automatically presented an attention getter, and when infants’ attention was regained, the following trial was started. We counted as “trial” each event between two consecutive look-away. Habituation criterion was reached when the average looking time of the last 3 consecutive trials decreased at least by 50% compared to the average looking time of the first 3 trials. Once the infants showed habituation to the first video, the Habituation phase of the second one started. Following the two habituation phases, infants viewed the three test trials, coded online in the same manner as the habituation trials (i.e., each test trial was stopped whenever the infant looked away for more than 2 seconds) (Figure 2).

Participants were video recorded throughout the presentation. To assure the reliability of the online coding, 25% of the videos were also coded offline frame-by-frame by a second blind coder using the software Datavyu (Datavyu Team (2014). Datavyu: A Video Coding Tool. Databrary Project, New York University. (http://datavyu.org). The inter-coder agreement (Pearson correlation) between the two coders for total fixation time was 0.99 in the habituation phase and 0.88 in the test phase; the Intra-Class Correlation (ICC) coefficient was of 1 in the habituation phase and 0.87 in the test phase (all $p < 0.001$), indicating overall a good inter-rater reliability (Koo & Li, 2016).

Results

All statistical analyses were performed using Jamovi 1.2.22 (https://jamovi.org) and conducted on a .05 level of significance (two-tailed). When the repeated-measures analysis of variance (ANOVA) yielded significant effects, post-hoc comparisons were Bonferroni corrected (Abdi, 2010). Whenever looking times did not respect normality assumptions, non-parametric tests were adopted.

The mean habituation time for the final sample was of $M = 143$ s; $SD = 58.73$ for the first habituation and $M = 91.5$ s; $SD = 52.59$ for the second habituation. Although the fixation times for the two habituations were significantly different (W (20) = 192, $p = 0.007$, $d = 0.68$), this is intuitively motivated by a decrease in infant’s attention, due to the high demands of a double habituation phase. In order to be sure that both associations were sufficiently encoded by infants, a paired sample t-test was performed to compare the fixation time in the last three trials only of both habituations. Results confirmed that mean looking times did not differ ($p>0.2$). Mean looking times were also consistently smaller in the last three compared to the first three trials (first habituation: W (20) = 227, $p < 0.001$, $d = 1.4$; second habituation: W (20) = 212, $p < 0.001$, $d = 0.9$) for both habituations, confirming that habituation criterion was reached. Despite a small decrease of attention, the two habituations can be therefore treated as comparable (Figure 3).

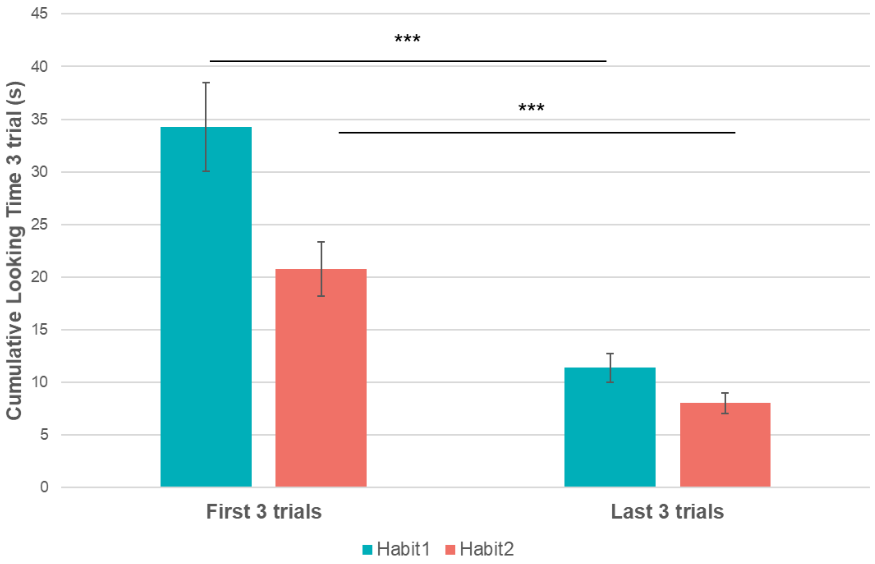

Figure 3. Fixation times for the two habituations. Although they were significantly different (*W* (20) = 192, *p* = .007, *d* = 0.68), the fixation times in the last three trials did not differ between the two habituations ($p>0.2$). Mean looking-times were also consistently smaller in the last three compared to the first three trials (first habituation: *W (20) = 227, p < 0.001, d = 1.4*; second habituation: *W (20) = 212, p < 0.001, d = 0.9*) for both habituations. Despite a small decrease of attention, the two habituations show to have the same trend.

Given that not all data were distributed normally, a non-parametric repeated-measures ANOVA (Friedman test) was then performed on the average looking times with Test Trial (familiar, violation, novel) as within-subject factor. A main effect of Test Trial was found, χ^2 (2) = 19, $p <$ 0.001. Pairwise comparisons revealed that the **Familiar** trial showed lower looking times both than the **Novel** (*t* (20) = 5.69, $p < 0.001$, *d* = 1.2; $M_{familiar}$ = 11.07 s, $SD_{familiar}$ = 62.05; M_{novel} = 24.83 s; SD_{novel}= 12.32) and the **Violation** (*t* (20) = 2.24, *p* = 0.031, *d* = 0.6; $M_{violation}$ = 16.63 s, $SD_{violation}$ = 10.1) test trial. The **Novel** event was also looked at for longer than the **Violation** (*t* (20) = 3.46, *p* = 0.001, *d* = 0.86) (Figure 4).

Overall, these results confirm that infants were habituated to the videos presented, and that they detected the novel action-sound pairs, as shown by a significant increase in looking times in the violation as compared to familiar trial in the test Phase. More interestingly, they also looked at the invented action-sound pairs longer than the familiar ones, indicating that they detected the difference, although this was not as interesting as the completely novel stimuli.

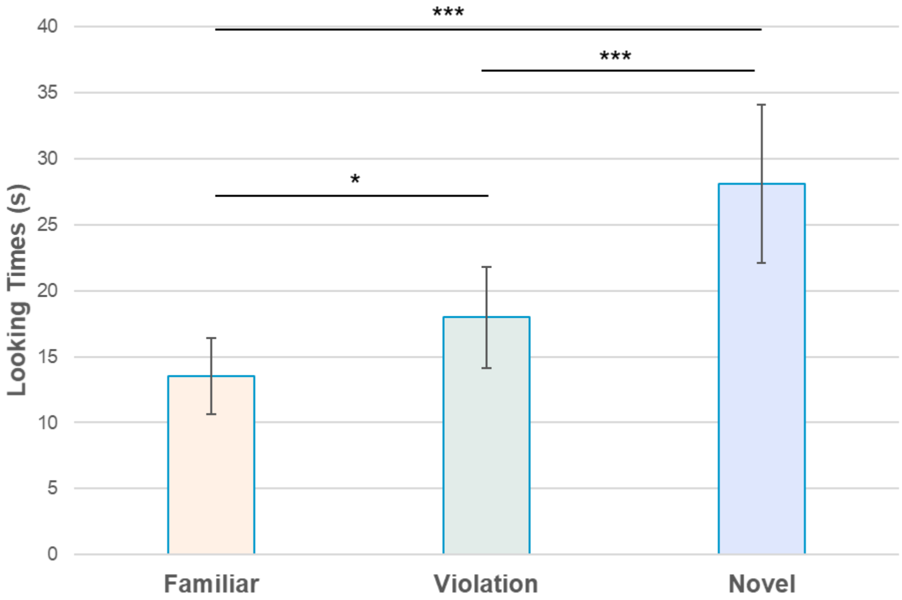

Figure 4. The Friedman test on the average looking times for the three test trials revealed lower looking times for the familiar test trial compared to both the novel (t (20) = 5.69, p < 0.001, d = 1.2; $M_{familiar}$ = 11.07 s, $SD_{familiar}$ = 6.21; M_{novel} = 24.83 s, SD_{novel}= 12322) and the violation (t (20) = 2.24, p = 0.031, d = 0.6; $M_{violation}$ = 16.63s, $SD_{violation}$ = 10.1) test trial. The novel event was also looked at for longer than the violation (t (20) = 3.46, p = 0.001, d = 0.86).

Control Study

The results found in the experimental study point out that, not only the novel situation is detected by infants' attention, but the inverted pairs as well. This strengthens our hypothesis that social interactions constitute a facilitating effect in infants' encoding of dynamic actions-effects associations.

While this was an innovative result when compared to the evidence found with objects (Perone et al., 2016), it remains unclear what might have facilitated this result. On one hand, one might argue that the social exchange is indeed what increases infants' attention, and in turn a heightened attention allows a better encoding of the action-sounds associations. On the other hand, it might also be true that what is successfully encoded is a contingency between actions and sounds, without necessarily relying on a “social exchange” facilitation.

To the purpose of disentangling this matter, we designed a control study where a similar situation was presented, but the interactive setting was manipulated in a way that it did not result as a natural dynamic (i.e., the sound was not presented as a social response, but as an external occurrence). We expected to replicate the novelty effect given by the Novel situation when compared to both the Familiar situation and the Violation. When comparing the Familiar and the Violation tests, our hypothesis was that the lack of a natural social situation would make the task of encoding the associations harder, resulting in a not significantly different looking behavior than the Familiar test phase.

Methods

Participants

The final sample consisted of twenty-one 10-month-old infants (mean age = 10 months and 4 days, *SD* = 5 days, 8 males). Participants were recruited in the area of the metropolitan city of Milano, Italy; they were born full term and did not have any history of neurological or significant medical condition, as reported by the parents on a questionnaire administered before the testing. Three additional infants were tested but excluded from the final sample because of test trials looking times above 2.5 standard deviations from the mean of the sample (*M* = 14.2, *SD* = 9.9) (n=1), or incomplete procedure because of fussiness and lack of attention (n=2). Prior to the testing sessions, all parents were given information about the study and gave their written consent, according to the ethical standards of the Declaration of Helsinki (BMJ 1991; 302:1194 and later amendments). The ethics committee of the University of Milano - Bicocca approved the study.

Stimuli and design

The set of stimuli used were the same described for the experimental study, again presented in a double habituation paradigm. Infants were shown first a chosen action-sound pair, looped until habituation criterion was reached, then a second action-sound pair, again until habituated. The three Test trials were one of the familiar videos (Familiar Trial), an inverted action-sound association (Violation Trial) and a novel association (Novel Trial). The familiar video presented was either the first or the second one the infants were habituated to, in a counterbalanced order between infants, and half of the infants saw the inverted video first, half of them saw the novel video first.

Contrarily to the experimental study, in the control study the onset of the vocalization (the same sounds previously used) was set at the beginning of the video. While the actress moving behaved in the same was, the second person present on the scene in this case did not articulate the vowel heard. By doing so, the actions and the sounds presented did not vary, while the social exchange mechanism was disrupted (Figure 5).

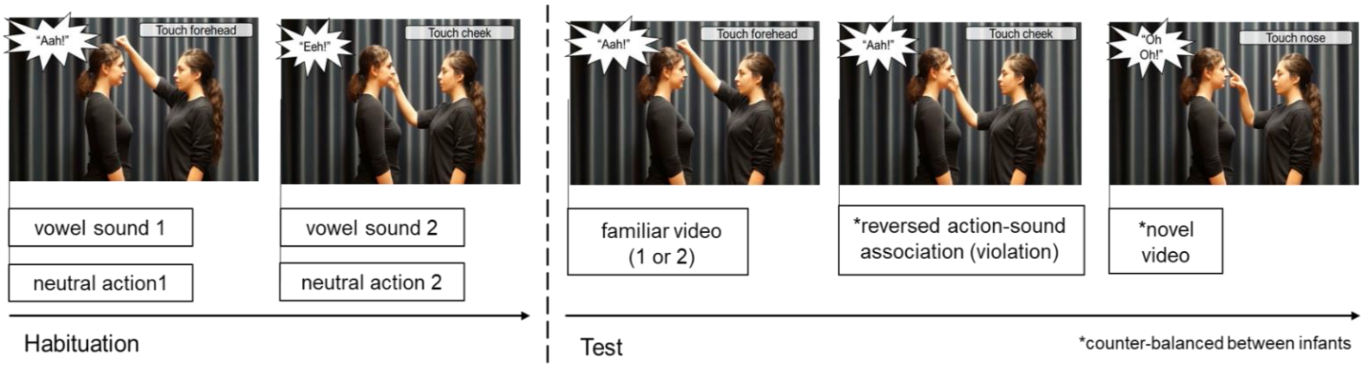

Figure 5. Example of a presentation in the control study. The number of trials for each habituation was determined by the infants' online watching behavior: when habituation criterion was reached (i.e., average looking time of the last 3 consecutive trials decreased at least by 50% compared to the average looking time of the first 3 trials) the second video was presented. Whenever participants looked away for more than 2 seconds, another trial was presented. Between each trial an attention getter appeared and, when infants' attention was regained, the following trial was started. This study differed from the previous one in the vowel presentation: the

All the parents of the control studies were also asked if their infants were able to perform actions and vowels similar to the ones presented (Rochat & Striano, 2000; Jacquey et al., 2020). Similarly to the previous sample, 100% of the infants were reported to produce the vowel "a", 95.2% the vowel "e" and 57.1% the vowel "o". As for the presented actions, 81% of the infants were reported to actively produce pointing, 95.2% the caress and 71.4% the closed fist movement.

This confirmed that most infants again had some first-hand experience of what they observed, although with different frequencies.

Procedure

Procedure was carried out in the same setting as the experimental sample. To assure the reliability of the online coding, 25% of the videos were also coded offline frame-by-frame by a second blind coder using the software Datavyu (Datavyu Team (2014). Datavyu: A Video Coding Tool. Databrary Project, New York University. (http://datavyu.org). The inter-coder agreement (Pearson correlation) between the two coders for total fixation time was 0.99 in the habituation phase and 0.99 in the test phase; the Intra-Class Correlation (ICC) coefficient was of 0.95 in the habituation phase and 0.99 in the test phase (all $p < 0.001$), indicating overall a good inter-rater reliability (Koo & Li, 2016).

Results

All statistical analyses were performed using Jamovi 1.2.22 (https://jamovi.org) and conducted on a .05 level of significance (two-tailed). When the repeated-measures analysis of variance (ANOVA) yielded significant effects, post-hoc comparisons were Bonferroni corrected (Abdi, 2010).

The mean habituation time for the final sample was of $M = 109.78$ s; $SD = 39.54$ for the first habituation and $M = 99.02$ s; $SD = 47.55$ for the second habituation. The fixation times for the two habituations did not result to be significantly different (W (20) = 144, $p = 0.34$, $d = 0.31$). In order to be sure that both associations were sufficiently encoded by infants, a paired sample t-test was performed to compare the fixation time in the last three trials only of both habituations. Results confirmed that mean looking times did not differ ($p = 0.41$). Mean looking times were also consistently smaller in the last three compared to the first three trials (first habituation: W (20) =

0.00, *p* < 0.001, *d* = -1.78; second habituation: *W* (20) = 1, *p* < 0.001, *d* = -1.56) for both habituations, confirming that habituation criterion was reached (Figure 6).

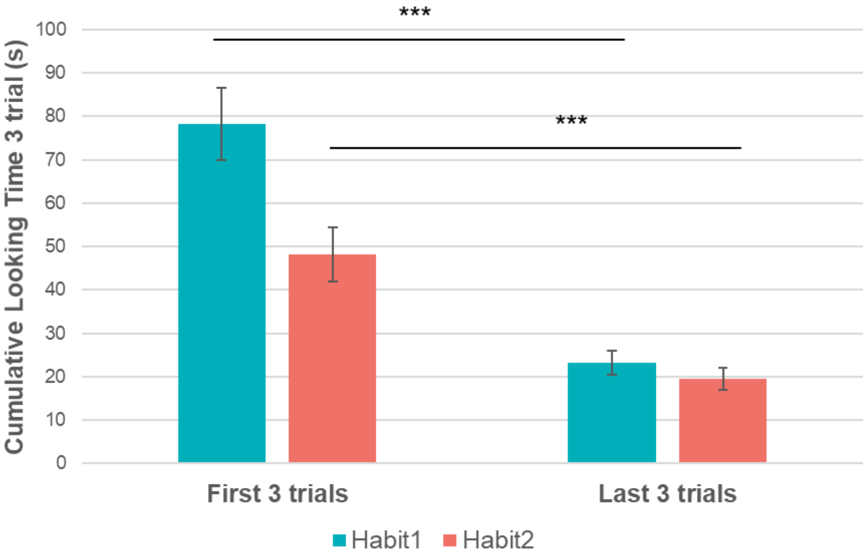

Figure 6. Fixation times for the two habituations. They did not differ significantly (*W (20) = 144, p = 0.34, d = 0.31*), and the fixation times in the last three trials did not differ between the two habituations (*p*>.05). Mean looking times were shorter in the last three compared to the first three trials ((first habituation: *W (20) = 0.00, p < 0.001, d = -1.78*; second habituation: *W (20) = 1, p < 0.001, d = -1.56*) for both habituations.

Given that, again, not all data were distributed normally, a non-parametric repeated-measures ANOVA (Friedman test) was then performed on the average looking times withTest Trial

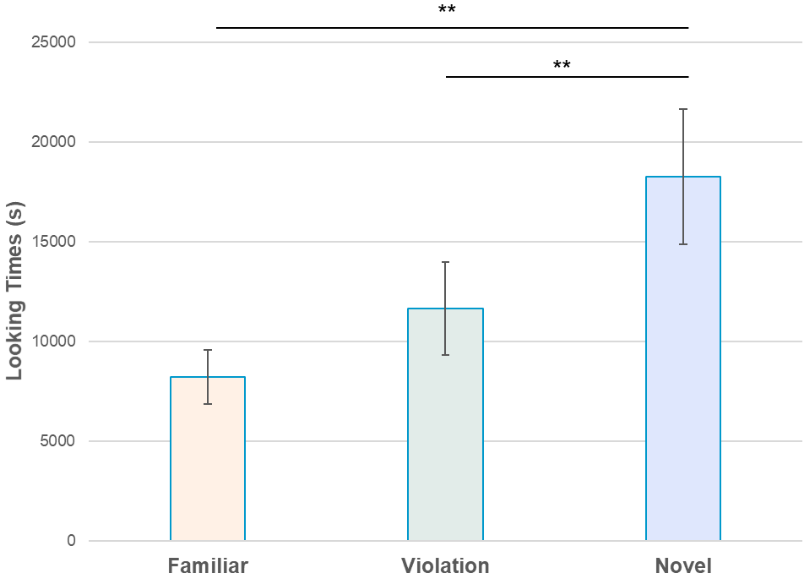

Figure 7. The Friedman test on the average looking times for the three test trials revealed lower looking times for the familiar test trial compared to the novel (*t* (20) = -2.65, *p* = 0.012, *d* = -0.55; $M_{familiar}$ = 8.2 s, $SD_{familiar}$ = 6.15; M_{novel} = 18.25 s; SD_{novel}= 15.48) test trial. The novel event was also looked at for longer than the violation (*t* (20) = 2.13, *p* = 0.026, *d* = 0.39; $M_{violation}$ = 11.64 s; $SD_{violation}$= 10.73).

(familiar, violation, novel) as within-subject factor. A main effect of Test Trial was found, χ^2 (2) = 19, *p* = 0.027. Pairwise comparisons revealed that the **Familiar** trial showed lower looking times than the **Novel** (*t* (20) = -2.65, *p* = 0.012, *d* = -0.55; $M_{familiar}$ = 8.2 s, $SD_{familiar}$ = 6.15*;* M_{novel} = 18.25 s; SD_{novel}= 15.48) test trial. The **Novel** event was also looked at for longer than the **Violation** (*t* (20) = 2.13, *p* = 0.026, *d* = 0.39*;* $M_{violation}$ = 11.64 s; $SD_{violation}$= 10.73) (Figure 7). In this case, no difference was detected between familiar and the violation test trial (*p* = 0.74).

Discussion

Previous literature showed how infants learn about object properties by linking actions performed on objects and multimodal appearances of the objects (Perone & Oakes, 2006; Perone et al., 2016). The sound outcomes were not observed to be relevant in the construction of such associations, so that infants were not able to associate an action performed on the object to a certain sound outcome.

The social domain is intrinsically multimodal, and the sounds are a fundamental part in the comprehension of other’s emotional and mental states (Robinson & Sloutsky, 2010; Grossmann, Striano & Friederici, 2006; Kahana-Kalman & Walker-Andrews, 2001). The aim of this study was to investigate whether, in a social setting, the action-sound association is perceived as relevant and used towards the construction of interactive scripts. To this aim, 10-month-old infants were habituated to two different action-sound associations and were then presented, as a test phase, a familiar association followed by an inverted one and then by a completely novel one. Looking times were recorded and analyzed. Results of the test phase looking times confirmed that infants looked only briefly at the familiar association, and longer to the novel association, demonstrating both the encoding of the habituated stimuli and the detection of novel settings. The interesting outcome was that infants looked longer at the inverted test trials as well (i.e., the one where both the action and the sound were previously presented, and infants were therefore familiar with them individually but not with how they were linked with each other) when compared to the familiar stimuli. The violation was detected, although not considered as salient as the completely new pairs.

Two possible lines of reasoning might explain this finding. One, as we hypothesized, the observation of social exchanges leads to a deeper encoding than the one observed when actions on inanimate objects are at play. The debate of how the domain of objects and people are processed is one of the most animated. Although people and objects indeed share some physical properties, they also have relevant differences: only people talk, express emotions, have a theory of mind, act based on social expectations or intentions, and communicate amongst themselves. But, despite all this added complexity, infants present a social cognition early on and distinguish between animate and inanimate objects (Legerstee, 1992; Molina, Van de Walle, Condry & Spelke, 2004). Not only do they distinguish, but a proper “social dominance” could be hypothesized, and this would allow the formation of expectations that are abstract enough to be applicable to new situations as well (Mascaro & Csibra, 2012). In a similar way, the results of our study suggest that the social relevance fosters the formation of expectations that are expected to be respected in following interactions.

One second possible interpretation might be that the associations learned were driven not by the social relevance of the situation, as we hypothesized, but by perceptual changes (Cashon & Cohen, 2000) or other forms of probabilistic inference and statistical sampling (Wellman, Kushnir, Xu & Brink, 2016). Children have indeed a strong bias towards causality between physical events (Bullock, 1984; Kushnir & Gopnik, 2007; Buchanan & Sobel, 2011), and disambiguating between a similar mechanism and a formation of a social script would help verifying if this mechanism is prevalent for infants as well.

For this purpose, we designed the control study, where the vocal reaction of the second actor was not visually paired with the opening of the mouth, and the onset of the sound preceded the unfolding of the action. This disrupts the perception of the sound as a response to the gesture. Rather, it appears that the sounds are happening concurrently but from an external source in the environment. Results showed that, while the familiar action – sound pairs observed were still perceived as familiar and the novel ones were still more interesting to infants because of their perceptual novelty, the violation test phase was not observed more than the familiar associations. These results strengthen our first interpretation. When complex action-sound associations happen in the context of an interaction, the “social dominance” allows for a more accurate encoding of all aspects of the scene.

To sum up, the present study confirms that interactive contexts, where two people act and an outcome is elicited by such actions, are already successfully encoded at 10 months of age. Previous studies on a similar age group seemed to suggest that, in order to have a similar efficacy in goal’s encoding, infants needed to be active participants in the exchanges (Henderson et al., 2013). Our study indeed suggests that this is not fundamental, and that the development of prediction on social interactions’ multimodal associations is well under way by the only observation of others’ actions and responses to them. Future studies might contribute to clarifying what processes, like social cognition, perceptual causality, or a motor prediction system are most involved in such mechanism.

This chapter contributed to showing how the observation of people moving can be used in a social setting to learn about interactive scripts. Movement and sounds are not just something that infants perceive, but they are inscribed in a social world that allows a deeper interpretation than only sensory processing would. The next chapter will move along this line by focusing on the link between actions performed and their social setting in its more powerful expression: emotions.

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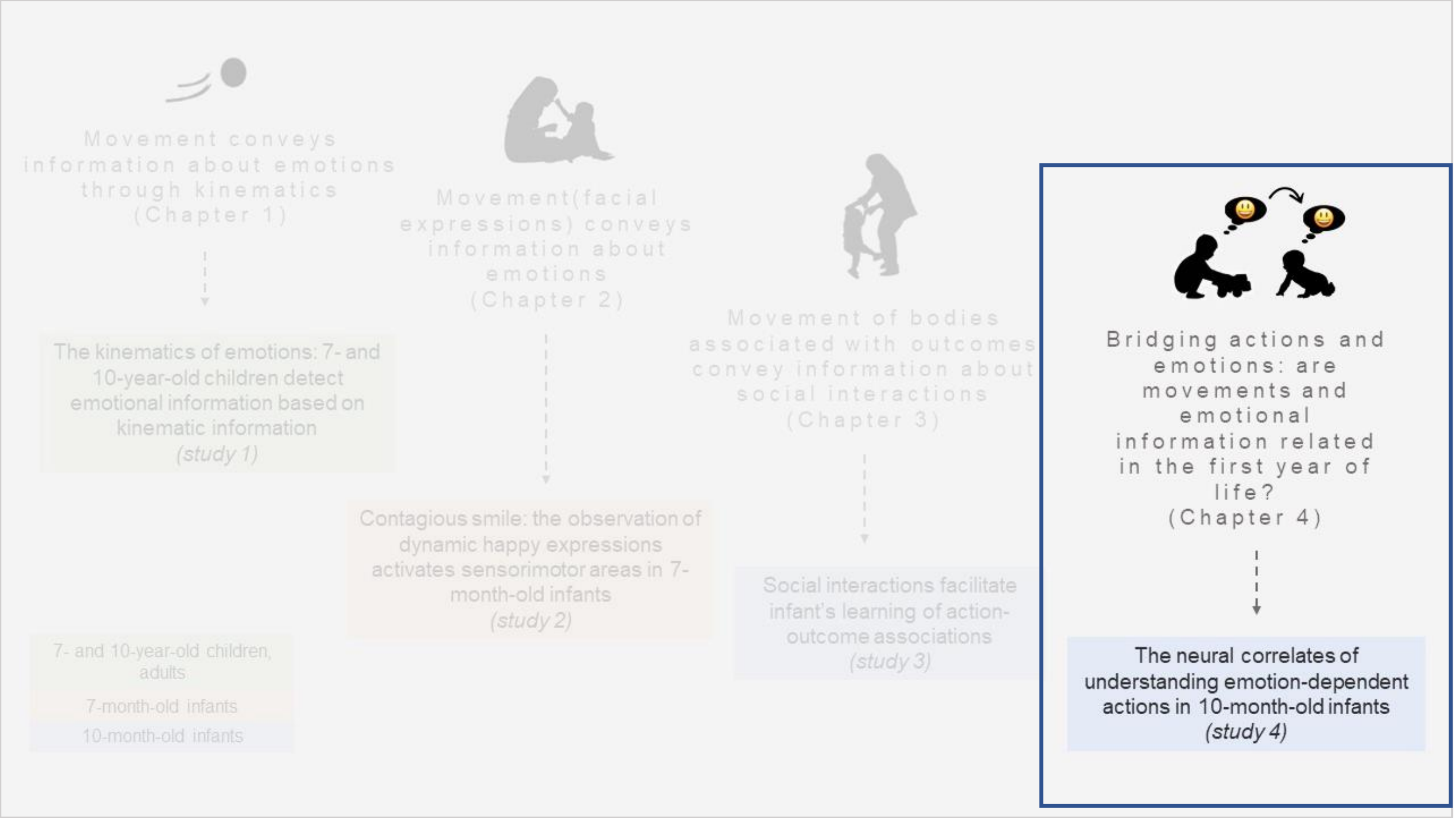
Chapter 4. Bridging actions and emotions: are movements and emotional information related in the first year of life?



The neural correlates of understanding emotion-dependent actions in 10-month-old infants (Study 4)[4].

In the previous chapters we laid out how children process kinematic information about different emotions (Chapter 1), how movement is a key feature towards infants' recognition of emotions displayed (Chapter 2) and how they encode movement as part of social interactions (Chapter 3).

These studies contribute to an already wide literature on social and emotional development. Nonetheless, little attention is generally devoted to how the two domains of actions and emotions are mutually influencing each other. From very early on in life, infants show the surprising ability to use a great deal of information to predict future events, whether it is actions and objects perception (Hunnius & Bekkering, 2014; Von Hofsten, Kochukhova & Rosander, 2007) or social interactions (Adamson & Frick, 2003). Action understanding is fundamental for acquiring information on the laws that regulate everyday life, both at an individual and at a collective level. Many actions in fact require more than one person and have an important social value. Similarly, emotions are something that can be felt and expressed at an individual level alone, but they become much more powerful when expressed to others and used as a meaningful communication tool. Actions are in turn often embedded in an emotional context, which reveals both the internal states of another person and the intention behind a specific action (Addabbo & Turati, 2020). Indeed, 6-month-olds infants process differently an action if performed in an emotional context (happy and angry) or in a neutral one, as the emotional context might be a cue indicating that the action is a particularly relevant source of information (Addabbo & Turati, 2020). In the following study we were interested on further investigating whether a similar emotional information is used to form predictions on what would happen after. In other words, one possibility is that 10-month-old infants decode the situation they are facing as something like: "The person I was watching clearly showed that this green object is disgusting. Surely, he will not want to hold it any longer…oh no, he is!" A different possibility is

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[4] Parts of this chapter are included in Roberti, E., Turati, C., Hoehl, S. (*In prep.*) The neural correlates of understanding emotion-dependent actions in 10-month-old infants.

that the emotional context only adds interest to the scene no matter whether is a disgusting or a happy one.   Emotions not only indicate what another person is feeling and thinking, but importantly they are cues towards the choice of which actions are more appropriate in a certain situation. This is true for adults as well as for children and even infants. Much about emotions has already been described in the previous chapters of this thesis. Importantly, electrophysiological studies contributed greatly to our understanding of emotional development. For instance, when exploring their multi-modal nature, Grossmann, Striano & Friederici (2005) examined 7-month-old infants' processing of emotional prosody: semantically neutral words were pronounced with either a happy, angry, or neutral tone of voice. Event-related potentials (ERPs) suggested a greater allocation of attention to angry tones, as in this condition a more negative response was elicited. Another component was observed, a positive slow wave (PSW) elicited by angry and happy prosody over temporal sites, that indexed enhanced sensory processing of the emotional stimuli. When they examined the same age group infants’ ability to process emotionally congruent and incongruent face–voice pairs (Grossmann, Striano & Friederici, 2006), they observed changes in function of crossmodal emotional congruity in the amplitude of two components: a negative component (Nc) and a subsequently elicited positive component. Specifically, these components were modulated by the congruence between tone of the voice and facial expression: the Nc elicited was more negative in incongruent pairs, while the positive component was larger for emotionally congruent words. These findings provide evidence that by 7-months of age infants combine different sensory modalities in the recognition of emotions, confirming behavioral results previously described (Walker, 1982; Soken & Pick, 1992). An additional ERP study by the same authors (Grossmann, Striano & Friederici, 2007) studied the development of facial expressions processing between 7 and 12 months of age. In 7-month-olds, a larger anterior (frontal and central) negativity was found in response to happy compared to angry faces, while in 12-month-olds a larger negativity to angry compared to happy faces was observed at posterior (occipital) electrodes. This difference in topography might reflect different neural processes for the two age groups: allocation of attention to happy faces for the 7-month-olds and a greater sensitivity in the visual cortices to angry faces for the older infants, probably due to a greater visual processing. A similar activation in the visual cortices might be lacking in younger infants because they tend to avoid looking at the angry and hence threatening face, or because they might have simply not been exposed to angry faces enough to understand the social meaning that they convey (Campos et al., 2000). By 12-months of life the cortical responses begin to appear more adult-like, characterized by a faster detection of threatening compared with friendly faces (Schupp et al., 2004).

Notably, around the 1-year- mark infants not only begin to have a deeper comprehension of emotions but also actively use emotional information to regulate their behavior and interpret external events. By the end of the first year, infants also use others' expressions (conveyed by both face and voice) to interpret external events and find causality between expressions and environmental events. In order to do this, they need to understand that a social message relates to a specific event determined by the emoter and that the referential cues can be used to infer something on a certain event or object (Moses, Baldwin, Rosicky & Tidball, 2001). This phenomenon is known as *social referencing* and can be studied in participants as young as 12 months using the 'visual cliff' experiment: they cross more often a deceptive drop (with a Plexiglas surface providing invisible support) if their mother is expressing happiness or interest instead of fear or anger (Sorce, Emde, Campos, & Klinnert, 1985; Vaish & Striano, 2004). Thus, infants around this age have demonstrated the ability to collect information and regulate their behaviour. For instance, Walden & Ogan (1988) reported that 10 to 13-month-olds use their parents' positive and fearful expressions inhibiting their approach to a toy only in the latter condition.

Moses et al. (2001) pointed out that the temporal contiguity could be responsible for the observed social referencing effects. To disambiguate this aspect, they asked an experimenter to enact an emotion, either referring to a novel object that was in-view (the experimenter sat in the room) or vocally expressing the same emotion without referring to the object (from outside the room). Although both scenarios were characterized by temporal synchrony, 18-month-olds demonstrated social referencing only in the first case: they were more inclined to approach the object when the experimenter expressed pleasure compared to disgust. In contrast, the same expressions from an equally noisy but absent experimenter did not influence infants' proximity to the object. Thus, 18-month-olds rely on signs of referential intent from the emoter to determine whether the expressed emotions are relevant to the object and behave accordingly. This finding was fostered by the results of a second study. Both 12 and 18-month-olds, on hearing the emotional outburst of an experimenter, immediately checked the experimenter’s face and followed the gaze toward the appropriate object.

The modification of infants’ behaviour based on the emotional displays could both depend on a real understanding of the emotions, and merely result from an emotional contagion (Widen & Russell, 2008). In general, a true understanding of the emotion can be presumed only when infants use a person’s emotional state to create expectations about his/her behavior (Hepach & Westermann, 2013). For instance, Phillips, Wellman & Spelke (2002) investigated whether infants connect the information about an actor's affect to their actions. The actor was instructed to emote positively about one object but not about the other present in the scene, and then reached for the object that was looked at. In the test phase, half of the time infants saw the same actor smiling at an object that they had not seen before and then picking it up (consistent event) or smiling at the old familiar object but still picking up the new one (inconsistent event). 12-month-olds look longer at the inconsistent events. Therefore, they use cues from the actor's gaze and expression to determine which object would be grasped, recognizing that the actor is likely to take a hold of the object that had previously elicited a positive affect. Barna & Legerstee (2005) extended these findings to negative emotions. They showed that 9- to 12-month-olds understand that, if a person gazing towards an object is emoting positively, he/she might also want to act on it, while if that same person emotes negatively, there should not be such intention.

In the paradigms previously discussed, actors expressed an emotion towards objects and then performed an action. To clarify if the emotion is attributed to the object or to the action per se, Repacholi (2009) showed 15- and 18-month-old infants three different actors first performing an action with an object and then displaying an emotive reaction, both visually and vocally. Anger, which can be interpreted as a reaction to having performed an action on an object, was employed instead of fear or disgust, which are usually triggered from having merely encountered an object. Interestingly, infants were less likely to imitate the exact same action that they saw performed by the angry actors, although they still tended to manipulate objects in general with different actions.

Therefore, infants seem to have linked emotions to specific actions and not merely to the presence of an object.

In the action understanding domain, behavioral research has stated that infants' imitation of actions is strictly linked to the evaluation of social interactions (Gredebäck & Melinder, 2010; Gredebäck & Daum, 2015; Gergely, Bekkering & Király, 2002). Gergely et al. (2002) observed that 12-month-olds imitated an unusual action (turning on a lamp with one's forehead) significantly more when the observed person's hands were free, than compared to when they were restrained. Langeloh and colleagues (2018) measured 12- to 14-month-old infants' brain activity while they were observing the same kind of usual and unusual actions. Differences in mu power (6-9 Hz in infancy; Marshall & Meltzoff, 2011) were measured, as mu rhythm desynchronization is associated with motor activation and can also be referred to the generation of a prediction about actions (Saby, Marshall & Meltzoff 2012). Infants observed videos of adults demonstrating that their hands were either free or restrained, and in the test phase, the actors were turning on a lamp or a soundbox with their head or their hand. In the hands-free condition (i.e., when the actor did not present any constraint in the previous videos), infants displayed a reduced mu power in frontal regions in response to unexpected actions (head touch). As expected, in the hands-restrained condition the activation in the mu frequency band did not differ between the two action outcomes. The effect, found only for the hands-free condition, can be explained by the updating of prior action predictions, which reflects in increased motor activation. Thus, neural processes involved in action observation are influenced by the initial experience with these actions. Importantly, previous studies also investigated the sensorimotor activation in response to expected or unexpected actions and found the opposite pattern. A decrease in activation in the alpha frequency band over sensorimotor areas during action observation has been interpreted as activation of the motor system (e.g., Marshall & Meltzoff, 2011; Muthukumaraswamy & Johnson, 2004). A greater desynchronization was often found as associated with higher levels of motor experience (Cannon et al., 2014). Therefore, a mu-rhythm suppression could be associated with most common actions.

Other than imitation, actions are also influenced by emotion. In a study investigating this aspect (Barna & Legerstee, 2005), happy or unhappy actors expressed, using both face and voice, an emotion that could be either positive or negative towards objects in a pre-trial phase. In the post-test trial phase, when actors were picking up the objects in the inconsistent (i.e., a negative emotion was expressed towards that object) trials, 9- and 12-month-old infants looking time was higher compared to the consistent trials. Infants of both age groups are therefore able to use the emotional message of the actor to predict actions and understand that others' behaviors are not just movements but rather, they are directed toward specific goals which can be predicted relying on their emotional display.

As seen so far, the emotion, action and social referencing domains have widely been investigated. On the other hand, fewer studies face the challenge of clarifying how emotional information and actions are integrated in infants' brains (Addabbo & Turati, 2020). The present study aimed not only to see whether an action performed in an emotional context is relevant, but also to detect potential differences in processing actions preceded by different emotions.

The behavioral and neurophysiological findings regarding infants' early emotion (Grossmann et al., 2005; Grossmann et al., 2007) and action (Gergely et al., 2002; Langeloh et al., 2018) processing abilities laid out so far altogether show that infants, already from the end of their first year of life, start to build expectations on how they should behave or how other people are supposed to act based on emotional cues. Behavioral studies have also addressed the question of how the two domains are influenced by each other (Moses et al., 2001; Phillips et al., 2002; Barna & Legerstee, 2005; Repacholi, 2009). Less is known about the mechanisms involved. It could be hypothesized that attention mechanisms play a key role in this process. For instance, in a study 14-month-old infants were familiarized to an actress looking inside a cup and emoting positively (happily) or negatively (with disgust), while another cup was present on the scene but not regarded (Vaish & Woodward, 2010). The hypothesis was that in a subsequent test phase, infants would look longer at the actress reaching in the same cup if she previously expressed disgust, and in the unattended cup if she had expressed happiness towards the other one. The idea is that when a person displays negative emotions (such as fear or disgust) about an object, one would predict that she will *not* hold that object. Results on the other hand showed greater novelty preference when the actress reached into the unattended cup regardless of the emotion previously displayed. These findings suggested that infants were not relying on emotional cues, but they were rather using the emotional context merely as a generic attentional cue (Vaish & Woodward, 2010). Other authors suggest that emotional contagion is an important aspect to be considered (Feinman, 1982). Emotional contagion could be described as the tendency to automatically mimic others' emotional expressions, whether it is through faces, voices or even one's behavior. Towards the end of the first year of life, emotional contagion would display a negativity bias (Vaish, Grossmann & Woodward, 2008; Carver & Vaccaro, 2007), and this might cause changes in behavior even before voluntary control on it is present. To our knowledge, one aspect that remains to be explored is whether the information about an emotional context can be kept into working memory and used towards guiding infants' attention towards external events in their first year of life.

To our knowledge, only one electrophysiological study (Carver & Vaccaro, 2007) investigated how infants use caregivers' emotional expressions to guide their behavior in novel situations. Infants were first exposed to neutral objects, and the parents were trained to give them a feedback (happy, disgust or neutral) whenever they referenced to them. Infants were then, with a 20 minutes delay, presented with the image of the objects on a screen while ERPs were recorded. The event-related potentials revealed that 12-month-olds allocate more attention to stimuli associated with negative adult emotion than to those associated with positive or neutral emotion.

However, no study has yet specifically investigated the neural correlates of infants' early ability of linking others' emotions to their following actions. The goal of the present study was two-fold. Firstly, we aimed to investigate if infants process differently the two actions of holding an object and pushing it away, or if they are more in general processed as acting on an object. If the first case proves right, it might be hypothesized that the action of holding an object is more familiar for infants, as their instinct from 5 months of life is to explore everything with their hands or mouth (Gerber, Wilks, & Erdie-Lalena, 2010). Secondly, we wanted to understand if the emotional context in which an action takes place (and that precedes such action) is actively influencing its perception. This aspect could be deducted, through electroencephalographic (EEG) recordings, by looking at the components evoked by the attention allocation to a target event. We designed an affective priming paradigm, which refers to a facilitation in the target processing when the prime has the same valence as the target (Fazio, 2001). We provided an emotional information (Happiness or Disgust) in the priming phase and the action “To” or “Away” in the target phase. If the prime is able to influence the perception of the target, then the action should be perceived as congruent and incongruent with the context (a happy emotion directed towards an object would lead to the holding of the object, while being disgusted would be more likely followed by pushing it away and getting rid of the object), eliciting a different attentional response. If infants on the other hand are not able to detect such pertinence, results will not highlight differences in the neural responses.

Specifically, the components we expected are the following. A Negative central (**Nc**) at frontal and central electrode sites (larger for incongruent pairs) and a subsequently elicited positive component (larger for emotionally congruent pairs), as described in Grossmann et al. (2006) could be observed Another typical component that could be expected is a posterior N400-like component, traditionally linked to the violation of semantic meaning (Kutas & Hillyard, 1980) also been found in response to incongruency in affective priming paradigms (e.g., Kamiyama, Abla, Iwanaga & Okanoya, 2013). In similar paradigms, a late slow wave (**LSW**) is found as well, reflecting increased attention towards unexpected targets and is also interpreted as reflecting updating working memory (e.g., Zhang et al., 2010). This component has been observed as an enhanced positivity following incongruently prime targets, indicating elevated attention due to inconsistency of valence. As this component has been discussed as analogous to the P300, they might also have in common the fact that they index novelty detection dependent on the stimulus context (Chennu et al., 2013).

A second analysis to support the ERP results was planned: a time-frequency analysis in the alpha oscillatory band (6-9 Hz in infants, Debnath et al., 2019). A differential mu-rhythm for the two presented actions would support the hypothesis that these are encoded as substantially different motor plans.

We also analyzed the processing of the emotional displays, to see whether a differential response could be found. We expected a negative deflection (Nc) in the 400–600-ms latency interval in the frontal and fronto-central electrodes, and a positive waveform (Pc) in the 600-1000 ms latency interval and had its maximum at central and parietal electrode sites.

Methods

Participants

The final sample of this study consisted of thirty 10-month-old infants (*M*=10 months 15 days, *SD*= 14 days, 20 males). All infants did not have any history of neurological or significant medical condition, were born full term (between 37 and 42 gestational weeks), with a normal birth weight (>2500 g) and had intact vision and hearing abilities. Additional 32 infants were tested but excluded from the final sample due to loss of attention (n= 12), fussiness (n= 9), artifacts resulting in insufficient number of analyzable trials (n= 9) or technical problems (n= 2). This attrition rate of 50% is similar to other EEG studies with infants (DeBoer, Scott & Nelson 2007; Stets, Stahl & Reid 2012), especially those which used similar paradigms, highly demanding for infants' attention, due to the length of the trials and the requirements for artifact free data (e.g., Righi, Westerlund, Congdon, Troller-Renfree & Nelson, 2014). The study was preregistered (on the platform https://aspredicted.org/) approved by the ethical committee of the University of Vienna and parents gave their informed written consent before starting the experiment, according to the ethical standards of the Declaration of Helsinki (BMJ 1991; 302:1194). Parents received 6 euros as a reimbursement for their travel expenses, and infants received a small toy and a certificate of their participation.

Stimuli and design

The design of the experiment consisted in a priming phase where a 2000 ms video was shown, followed by a 300 ms interval, a 500 ms neutral frame and a 1400 ms target frame (Figure 1).

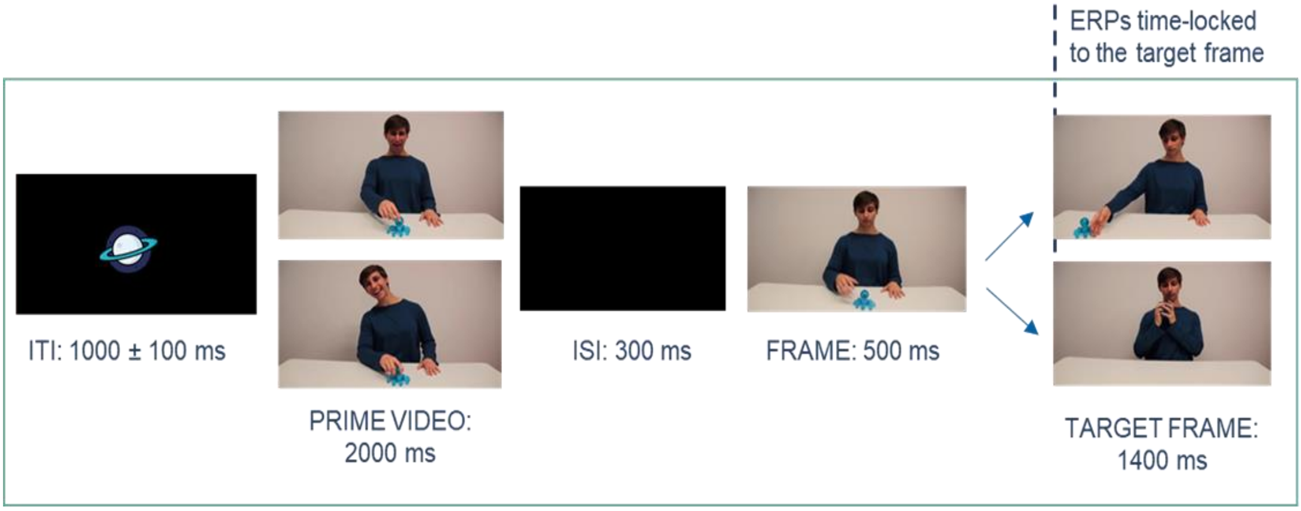

Figure 1. Trial structure. After an inter-trial interval (ITI) varied randomly between 1000 and 1100 ms, the video of an actor expressing happiness or disgust towards an object was played for 2000 ms. An inter-stimuli interval (ISI) of 300 ms was then followed by a neutral frame (for 500 ms) where the same actor is looking at the object previously displayed. Finally, the target frame where the actor is either holding the object or pushing the object away was shown for 1400 ms.

Priming video. In order to convey the information about an emotional display towards an object, we recorded 2000 ms videos of two actors (1 male, 1 female) expressing happiness or disgust towards six different unfamiliar objects. The objects chosen were a blue plastic octopus, an orange funnel, a green sponge, a red pepper mill, an orange plastic hedgehog, and a purple toy with a handle. These objects were chosen, as they are not too familiar for infants, in order to avoid a pre-existing affective valence. At the beginning of the scene, all the objects were placed at the centre of the screen, while the actor made eye contact with the observer to ensure attention engagement. After 5 frames, the actor looked at the object and started approaching it with his/her hand, reaching it at around 734 ms (22 frames). As the contact happened, the actor expressed through face, voice, and body one of two emotions: happiness and disgust, while their gaze shifted back to the observer.

Target frame. After a neutral frame of the actor looking at the same object shown in the priming phase was presented for 500 ms, the target frame appeared. One of two scenarios could be presented: either the actor would be holding the object closer to the body, or was pushing it away from it. The target frames were either congruent or incongruent with the priming stimuli, resulting in four conditions: happy – to (**HT**, congruent), happy – away (**HA**, incongruent), disgust – to (**DT**, incongruent), disgust – away (**DA**, congruent) (Figure 2).

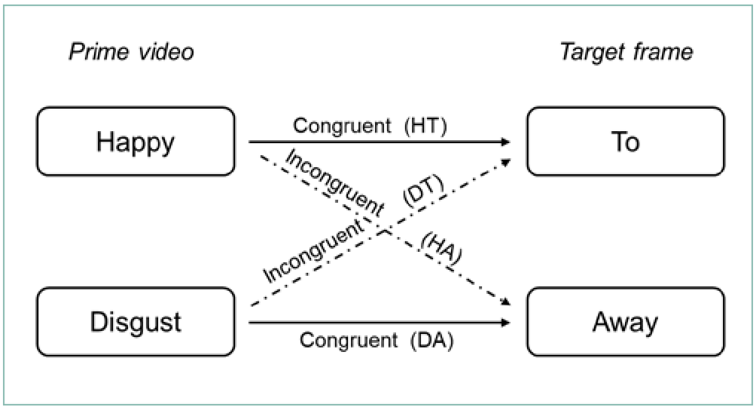

Figure 2. Schematic illustration of the prime-target stimuli combinations.

Procedure

Testing was performed in a dimly lit room and in order to avoid possible distractions participants were surrounded by blue curtains, hiding to their sight everything except from the screen. The stimuli were presented on a BENQ 21.5" screen (1920 x 1080 pixel resolution, 60 Hz refresh rate). Infants sat in their caregiver's lap at a distance of approximately 60 cm from the screen, forming a maximum visual angle of 19.51° vertically and 18.27° horizontally. The stimuli were presented in a pseudo-random order using an Opensesame script (http://www.cogsci.nl/opensesame), so that no more than three consecutive equivalent emotions, and no more than three congruent or incongruent consecutive pairs were presented. The total number of trials was of 96, for a total duration of around 10 minutes. A break could be taken when needed, and the procedure was stopped when infants showed signs of distress or whenever parents asked to interrupt. The mean number of trials presented was 92.87 (*SD*=8.07) (**HT**: *M* =

23, *SD* = 2.6; **HA**: *M* = 23.3, *SD* = 2.1; **DT**: *M* = 23.5, *SD* = 1.4; **DA**: *M* = 23.2, *SD* = 2). As shown by a non-parametric repeated-measures ANOVA (Friedman test), the number of presented trials did not differ between the four conditions (χ^2 (3) = 6.17, *p* = 0.1). To minimize the influence of external social cues, parents were asked to not point and interact with their infants.

The ERP analyses was therefore performed time-locked to the target stimuli, to investigate the processing of action performed and its possible interaction with the prime. A second analysis performed on the target phase was the time-frequency analysis, to explore whether a mu-rhythm desynchronization in response to one or both actions was present. Moreover, an ERP analysis was also performed time-locked to the presentation of the priming videos, to further explore how the emotional content was processed. Methods and analyses will be presented, chronologically, with the prime phase first, followed by the target phase.

Electroencephalogram recording and analyses

EEG was recorded continuously using a 32-channels ActiCap System (Brain Products GmbH, Gilching, Germany), with active electrodes arranged according to the 10-20 system, amplified through a BrainAmp amplifier, and recorded with BrainVision Recorder and Video Recorder software (Brain Products GmbH, Gilching, Germany). Impedances of the electrodes were checked before the beginning of the recording and were considered acceptable if lower than 20 kΩ. The signal was referenced online to the right mastoid (REF) reference channel and data was sampled at 500 Hz. Further offline processing was performed using Matlab, EEGLAB toolbox (Delorme & Makeig, 2004). The signal was band-pass filtered (0.3-30 Hz) and re-referenced to the left mastoid TP10. Following these preliminary steps, different segmentations followed according to the planned analysis. We therefore report separately the steps for ERP prime analysis, ERP target analysis and mu-rhythm target analysis.

Prime analysis – ERP

Data were segmented with a100 ms baseline before and 2000 ms after the onset of the videos. All the trials where the signal exceeded a voltage threshold of 200 µV within a 200 ms interval in the channels of interest (Michel, Wronski, Pauen, Daum, & Hoehl, 2017) were marked as bad. Artifacts, such as blinks, eye movements or other movements which cannot be automatically individuated, were again manually checked and, if necessary, rejected. A maximum of three individual bad channels of interest were replaced using spherical spline interpolation (bad channels replaced were the same replaced in the target analysis). Only the trials in which the prime was watched for more than 50% were included in the final analysis, to maximize the possibility that the emotional information was processed. Across participants, an average of *M*=11.1 trials per condition (*SD*=2.6) contributed to the average ERPs (**Happiness:** *M*=10.2, *SD*=2.9; **Disgust:** *M*=10.4, *SD*=3.1). Due to the longer time window, n = 4 subjects presented data with too much noise and had to be excluded from further analyses because they presented a low number of trials per condition (**Happiness:** *M*=5.2, *SD*=1.8; **Disgust:** *M*=5, *SD*=2). The final sample of included participants was therefore of 24 subjects.

Individual participant averages were computed separately for each channel across all trials within each condition. The clusters of electrodes corresponding to each region of interest (ROI) were: frontal (F3, Fz, F4), fronto-central (FC3, FCz, FC4), central (C3, Cz, C4) and parietal (P3, Pz, P4). According to the suggestion of a visual inspection of the waveforms, in this case we analyzed fronto-central and central electrodes separately. The waveform indeed suggested a negative deflection (Nc) in the 400–600-ms latency interval at frontal and fronto-central electrodes, and a positive waveform (Pc), in the 600-1000 ms latency interval at central and parietal electrode sites.

One important consideration must be kept in mind: the actors in the video started moving towards the object with a neutral face and, only after touching it, after 22 frames (734 ms), they started expressing the emotion. This was well mirrored by the waveforms we observed (see Figure 4 in the Results section). After a first deflection observed across all locations, there was a return to baseline and, after the onset of the emotion, other two components were observed: a negative central (Nc) frontally and fronto-centrally, and a positive component (Pc) centrally and parietally (Grossman et al., 2006). A preliminary analysis on the first negative deflection, between 200 and 400 ms after the onset of the video, was first conducted. Indeed, the component resulted to be significantly different than baseline as revealed by one sample T-Tests, **frontally** (*t* (23) = -3.40, *p* = 0.002, *d* = -0.7), **fronto-centrally** (*t* (23) = -3.44, *p* = 0.002, *d* = -0.7), **centrally** (*t* (23) = -3.51, *p* = 0.002, *d* = -0.72) and **parietally** (*t* (23) = -2.78, *p* = 0.011, *d* = -0.57). As expected, paired samples T-Tests revealed no differences between the two conditions (all *p*>0.4), given that the emotions were not yet expressed.

For this reason, in the results section we will lay out the results after the onset of the emotional display. For the sake of clarity, we will then refer to 0 ms as the onset of the emotion, and the remaining time window went up to 1266 ms.

Target analysis - ERP

Data were segmented into trials with 100 ms baseline (as in Patzwald, Matthes & Elsner, 2020) before and 1400 ms following the target stimulus onset. All the trials where the signal exceeded a voltage threshold of 200 µV within a 200 ms interval in the channels of interest (Michel, Wronski, Pauen, Daum, & Hoehl, 2017) were marked as bad. Artifacts, such as blinks, eye movements or other movements which cannot be automatically individuated, were manually checked and, if necessary, rejected. A maximum of three individual bad channels of interest were replaced using spherical spline interpolation. Only the trials in which the prime was watched for more than 50% were included in the final analysis, to maximize the possibility that the emotional information was processed. Across participants, an average of *M*=11.1 trials per condition (*SD*=2.6) contributed to the average ERPs (**HT:** *M*=11.3, *SD*=2.6; **HA:** *M*=10.8, *SD*=2.7; **DA:** *M*=10.3, *SD*=2.4; **DT:** *M*=11.8, *SD*=2.6). The number of rejected trials is mainly due to the length of the trials. Especially in the second half of the procedure when infants' attention naturally diminishes, eye and body movement happened more frequently during the target stimuli presentation. The number of trials that contribute to the final analyses is nonetheless in line with previous research using similar paradigms (Crespo-Llado, Vanderwert & Geangu, 2018; Hendrickson, Love, Walenski & Friend, 2019). Individual participant averages were computed separately for each channel across all trials within each condition. The clusters of electrodes corresponding to each region of interest (ROI) were as follows: frontal (F3, Fz, F4); fronto-central and central averaged together (FC3, FCz, FC4, C3, Cz, C4); and parietal (P3, Pz, P4) (Figure 3).

As previously mentioned, we expected an Nc component at frontal or central electrode sites between 400 and 600 ms (larger for the condition that attracted infants' attention the most). Visual inspection confirmed a similar although slightly wider time window (i.e., 350 to 650 ms) for our study. We then expected a subsequent positive component between 600 and 1000 ms as described in Grossmann et al. (2006). Another typical component that we expected was a posterior component between 400 and 600 ms, that has been reported in response to incongruency in affective priming paradigms (Kamiyama et al., 2013). Affectively incongruent trials were previously found to elicit larger N400 amplitudes than congruent trials. A similar effect was also interpreted as a spread activation within an evaluative-semantic network or integration (Kutas & Federmeier, 2011). The visual inspection of the waveforms did not confirm the expected time window. It rather indicated the presence of an ERP morphology in the 800-1100 ms time window. This seemed to be like the potentials found in studies that investigated stimuli familiarity and frequency with infants,

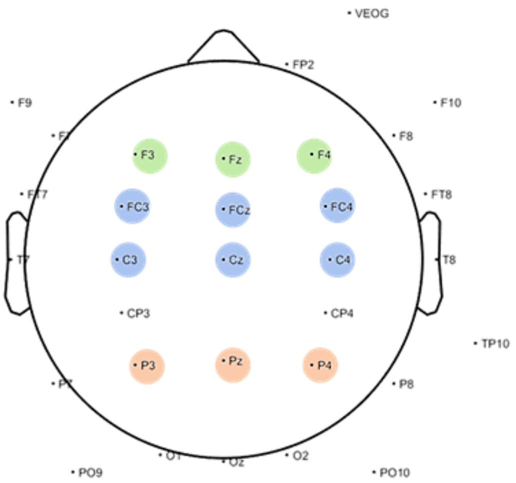

Figure 3. Schematic diagram of the 32-channels sensor layout. The clusters of electrodes corresponding to each ROI are represented: in **green** frontal (left: electrode F3; right: electrode F4; midline: electrode Fz); in **blue** central (left: electrode C3, FC3; right: electrode C4, FC4; midline: electrode Cz, FCz); and in **orange** parietal (left: electrode P3; right: electrode P4; midline: electrode Pz)

recorded around 900 ms post-stimulus onset (Richards, 2003; Wiebe et al., 2006). They defined such ERP as Late Slow Wave (LSW), and they found that novel stimuli elicited lower amplitude slow-wave activity than familiar stimuli (Wiebe et al., 2006).

Target analysis – Mu-rhythm

Data were segmented into trials from 1000 ms before the onset of the target and 1800 ms following the target stimulus onset. All the trials where the signal exceeded a voltage threshold of 200 µV within a 200 ms interval in the channels of interest (Michel, Wronski, Pauen, Daum, & Hoehl, 2017) were marked as bad. Artifacts, such as blinks, eye movements or other movements which cannot be automatically individuated, were manually checked and, if necessary, rejected. A maximum of three individual bad channels of interest were replaced using spherical spline interpolation. Only the trials in which the prime was watched for more than 50% were included in the final analysis, to maximize the possibility that the emotional information was processed. Due to the longer time window, n = 6 subjects presented data with too much noise and had to be excluded from further analyses because they presented a low number of trials per condition (**HT:** *M*= 2, *SD*=2.35; **HA:** *M*=4, *SD*=2; **DT:** *M*=3.94, *SD*=1.87; **DA:** *M*=2.8, *SD*=2.59). The final sample of included participants was therefore of 24 subjects.

Across participants, an average of *M*=11.6 trials per condition (*SD*=0.29) contributed to the average ERPs (**HT:** *M*=11.63, *SD*= 3.03; **HA:** *M* = 10.88, *SD*= 2.76; **DA:** *M*=11.88, *SD*= 2; **DT:** *M*=11.88, *SD*= 3.44).

Time-frequency analyses were performed on each artifact-free trial using continuous wavelet transform with Morelet wavelets at 1 Hz intervals in the 3–20 Hz range. In order to eliminate distortion created by the wavelet transform, the first and the last 400 ms of each segment were removed. A 500 ms baseline period from 600 ms to 100 ms before stimulus onset was selected. This baseline occurred during the neutral frame presented, which allowed to have an information similar and equally interesting to the experimental stimuli, but not contain the variable of interest (de Klerk & Kampis, 2021). Previous research showed that in infants, the peak frequency band reactive to movement is the 7–8 Hz band (Marshall and Meltzoff, 2011; Quadrelli, Geangu & Turati, 2019) and that reduced mu-power in the 6–8 Hz band can be observed in response to unexpected actions (Langeloh et al., 2018). Therefore, the averaged activity in the 6–9 Hz range during the 500 msec baseline was subtracted from averaged activity recorded during the target presentation. Average wavelet coefficients within infants were calculated by taking the mean across the trials. Other than frontal (F3, Fz, F4). Fronto-central (FC3, FCz, FC4), central (C3, Cz, C4) and parietal (P3, Pz, P4) electrodes, activity was also extracted from occipital (O1, Oz, O2) electrodes. Previous literature has shown how an activity in the alpha band is often found in this cluster of electrodes as related to visual attention, and therefore while this is expected to be present it is not expected to differ between conditions (Debnath et al., 2019, Warreyn et al., 2013). The distribution of all dependent variables was checked: statistical tests indicated that the distribution was normal (Shapiro-Wilk $p>0.05$).

Post-hoc comparisons were performed for all significant main effects and interactions and corrected for multiple comparisons (Bonferroni p values are presented). All statistical tests were interpreted at .05 level of significance (two-tailed). The Greenhouse-Geisser correction was applied whenever the assumption of Sphericity was violated (indicated by ε).

Results

Prime analysis – ERP

As a first step, we decided to investigate how infants processed the emotional information per se. We therefore analyzed ERPs in response to the videos where actors expressed happiness and disgust. The conditions included were not four anymore as in the target analysis, but two (happiness, disgust), as the action observed was always the same: the actor reached for the object and then expressed an emotion. Visual inspection (Figure 4) confirmed two possible components: a negative deflection (Nc) in the 400–600-ms latency interval in the frontal and fronto-central electrodes, and a positive waveform (Pc) in the 600-1000 ms latency interval and had its maximum at central and parietal electrode sites.

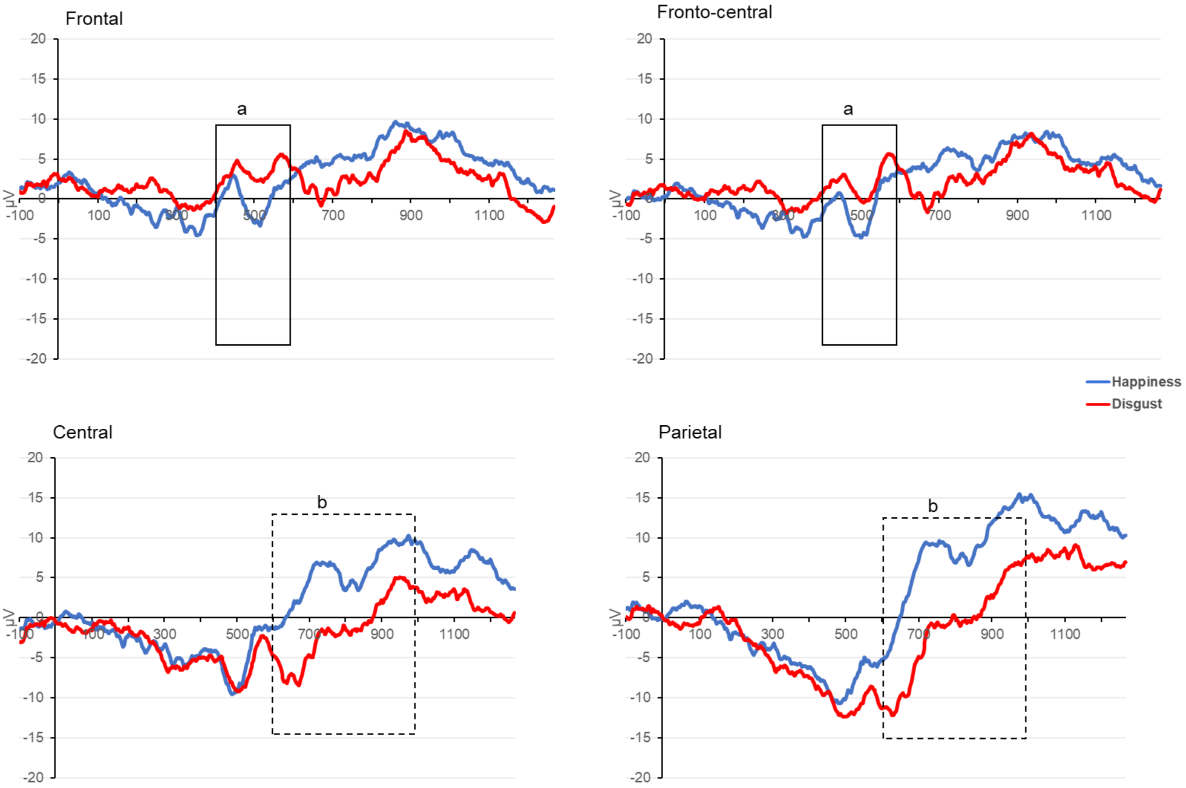

Figure 4. Waveforms representing potential evoked from the emotional displays presented in the priming phase. Specifically, **a)** a negative deflection (Nc) in the 400–600-ms latency interval in the frontal (left panel) and fronto-central (right panel) electrodes, and **b)** a positive waveform (Pc) in the 600-1000 ms latency interval at central (left panel) and parietal (right panel) electrodes.

Nc, 400-600 ms, frontal and fronto-central ROI

A visual inspection of the waveforms suggested a negative deflection (**Nc**) in the **400–600-ms** latency interval in the frontal and fronto-central electrodes, as previously found in similar studies (e.g., Grossmann et al., 2006; Striano et al., 2006). A repeated-measures ANOVA with Emotion (happiness, disgust) and Lateralization (left, midline, right) was performed for the two regions of interest separately.

In the **frontal ROI** a main effect of Emotion was not found (*p* = 0.089), but a main effect of Lateralization (F(2,46) = 6.29, *p* = 0.004, η^2_p = 0.22) showed that the voltage over midline was higher than both over left (*t*(23) = -2.88, $p_{bonferroni}$ = 0.014, *d* =-0.6) and right electrodes (*t*(23) = -2.91, $p_{bonferroni}$ = 0.009, *d* =-0.6) (M_{left}=0.94 µV; SD_{left}= 8.93; M_{rightt}= 0.74 µV; SD_{right}= 10.6; $M_{midline}$= 4.53 µV; $SD_{midline}$= 10.5). This effect was further qualified by a significant interaction between Emotion and Lateralization (F (2,46) = 5.75, *p* = 0.006, η^2_p = 0.2). Pairwise comparisons showed that this was only true for the happiness condition (all *p*<0.001) but not when disgust was observed (all *p*>0.2). Happiness evoked a higher voltage over midline ($M_{midline}$= 4.24 µV; $SD_{midline}$= 12.5) than both over left (M_{left}= -1.71 µV; SD_{left}= 11.52) and right (M_{rightt}= -1.28 µV; SD_{right}= 11.97) electrodes (Figure 5).

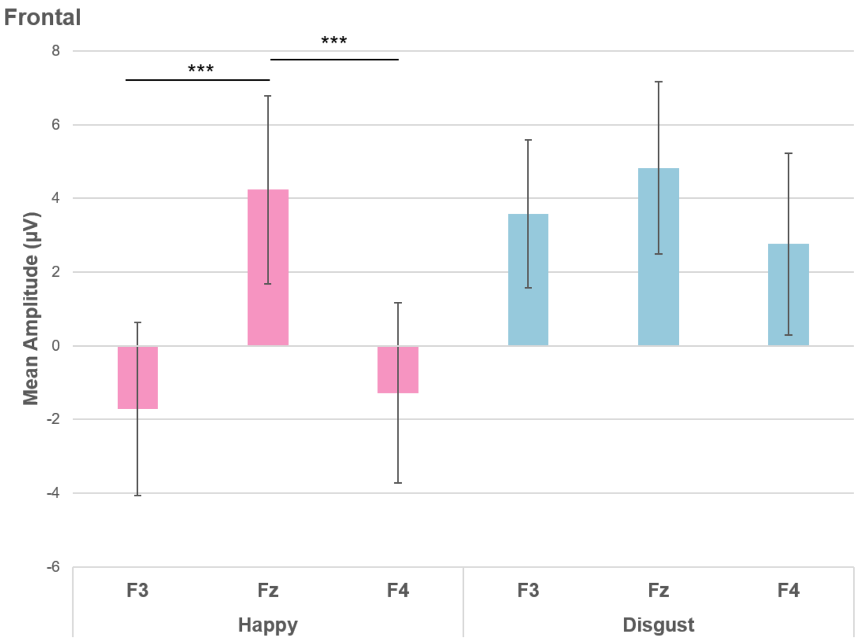

Figure 5. Mean amplitude, the Frontal left (F3), midline (Fz) and right (F4) electrodes for the two conditions (happiness and disgust). Asterisks (****p* < .001) illustrate that mean voltage is higher in the Happy condition over midline ($M_{midline}$= 4.24 µV; $SD_{midline}$= 12.5) than both over left (M_{left}= -1.71 µV; SD_{left}= 11.52) and right (M_{rightt}= -1.28 µV; SD_{right}= 11.97) electrodes.

These same results were found the **fronto-central ROI:** a main effect of Emotion was not found (p = 0.33), but a main effect of Lateralization (F(2,46) = 3.72, p = 0.032, η^2_p = 0.14) showed that the voltage over midline was higher over left electrodes (t(23) = 2.45, $p_{bonferroni}$ = 0.029, d =0.5) but in this case not over right electrodes (p>0.2) electrodes (M_{left}= -0.4 µV; SD_{left}= 9.11; M_{right}= 0.69 µV; SD_{right}= 9.64; $M_{midline}$= 2.6 µV; $SD_{midline}$= 9.61). This effect was further qualified by a significant interaction between Emotion and Lateralization (F (2,46) = 4.58, p = 0.015, η^2_p = 0.17). Pairwise comparisons showed that this was only true for the happiness condition (all p<0.001) but not when disgust was observed (all p>0.2). Happiness evoked a higher voltage over midline ($M_{midline}$= 2.82 µV; $SD_{midline}$= 11.8) than over left (M_{left}= -2.39 µV; SD_{left}= 11.4) electrodes (Figure 6).

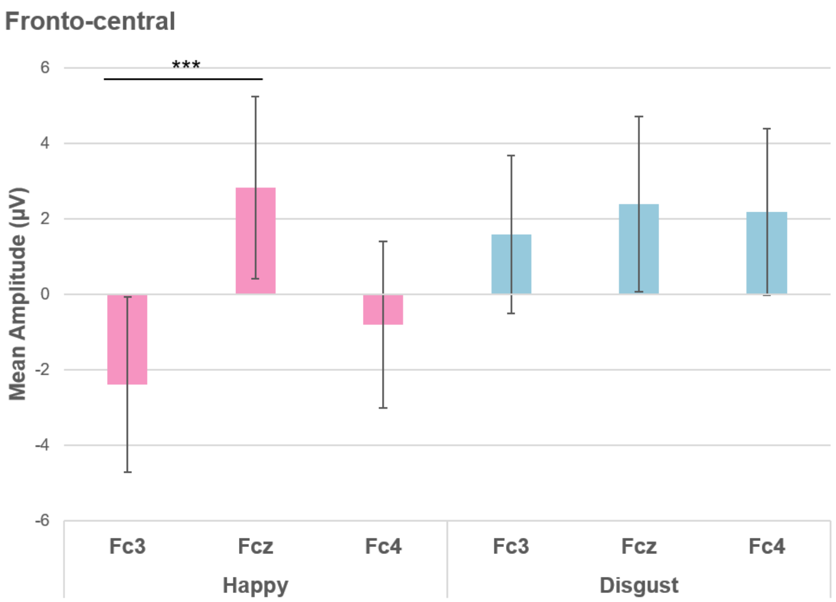

Figure 6. Mean amplitude, the Fronto-central left (Fc3), midline (Fcz) and right (Fc4) electrodes for the two conditions (happiness and disgust). Asterisks (***p < .001) illustrate that mean voltage is higher in the Happy condition over midline ($M_{midline}$= 2.82 µV; $SD_{midline}$= 11.8) than over left (M_{left}= -2.39 µV; SD_{left}= 11.4) electrodes.

Pc, 600-1000 ms, central and parietal ROI

As in Grossmann et al. (2006), we also observed a positive waveform (**Pc**), statistically significant in the **600-1000 ms** latency interval and had its maximum at central and parietal electrode sites. At **central ROI,** a main effect of Emotion was found (F (1,23) = 11.18, $p = 0.003$, $\eta^2_p = 0.33$). Post-hoc comparisons showed that the average voltage for happiness was higher than for disgust (t (23) = 3.34, $p_{bonferroni} = 0.003$, $d = 0.68$) ($M_{happiness}$=6.35 µV; SD$_{happiness}$= 10.28; $M_{disgust}$= 0.53 µV; SD$_{disgustt}$= 8.41) (Figure 7). No effect of Lateralization (p =0.3) or interaction between Emotion and Lateralization (p =0.7) was found.

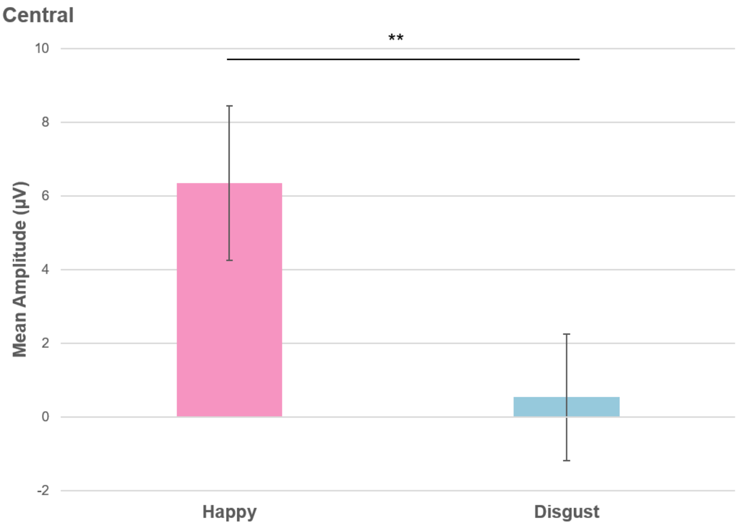

Figure 7. Mean amplitude, the Central electrodes for the two conditions (happiness and disgust). Asterisks (**$p < .01$) illustrate that mean voltage for happiness ($M_{happiness}$=6.35 µV; SD$_{happiness}$= 10.28) was higher than for disgust ($M_{disgust}$= 0.53 µV; SD$_{disgustt}$= 8.41).

Similarly, at **parietal ROI** a main effect of Emotion was found (F (1,23) = 14.32, $p < 0.001$, $\eta^2_p = 0.38$). Post-hoc comparisons showed that the average voltage for happiness was higher than for disgust (t (23) = 3.78, $p_{bonferroni} < 0.001$, $d = 0.77$) ($M_{happiness}$= 4.58 µV; SD$_{happiness}$= 11.16; $M_{disgust}$= -2.96 µV; SD$_{disgustt}$= 9.92). No effect of Lateralization (p =0.4) was found. An interaction between Emotion and Lateralization was found (F (2,46) = 4.3, $p = 0.019$, $\eta^2_p = 0.16$) Post-hoc comparisons showed that happiness was higher in voltage especially over midline (M_{Pz}= 6.27 µV; SD$_{Pz}$= 11.1), when compared to disgust in all regions of interest (M_{P3}= -2.92 µV; SD$_{P3}$= 10.6; M_{Pz}= -3.2 µV; SD$_{Pz}$= 10.7; M_{P4}= -2.75 µV; SD$_{P4}$= 9.54) (all $p_{bonferroni} < 0.005$) (Figure 8).

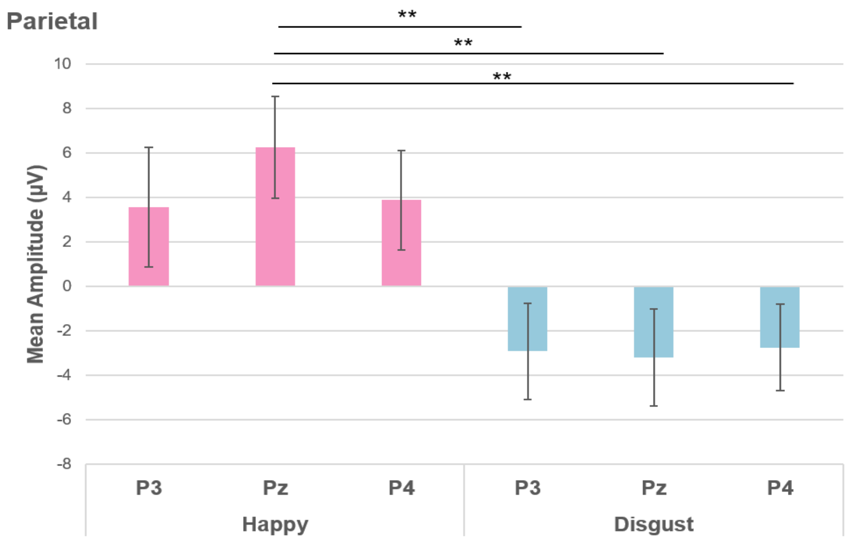

Figure 8. Mean amplitude, the Parietal left (P3), midline (Pz) and right (P4) electrodes for the two conditions (happiness and disgust). Asterisks (***p* < .01) illustrate that mean voltage for happiness was higher over midline (M_{Pz}= 6.27 µV; SD_{Pz}=11.1), when compared to disgust in all regions of interest (M_{P3}= -2.92 µV; SD_{P3}= 10.6; M_{Pz}= -3.2 µV; SD_{Pz}= 10.7; M_{P4}= -2.75 µV; SD_{P4}= 9.54).

Target analysis - ERP

From visual inspection a similar time window was identified (i.e., 800 to 1100 ms) for our study. Figure 9 shows the grand average of all participants at frontal, central and parietal ROI.

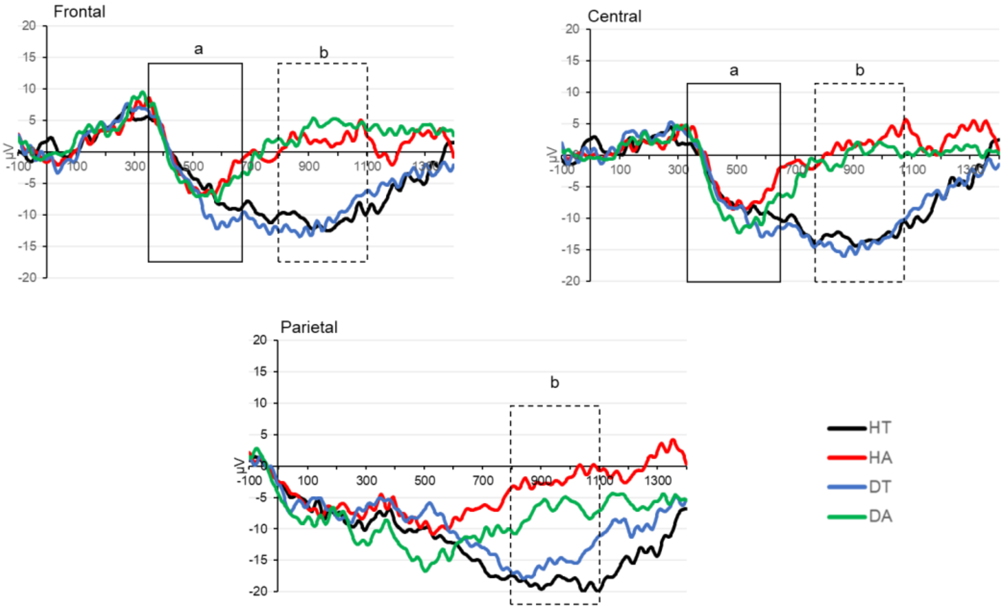

Figure 9. The ERPs for target timeframes at frontal, central, and parietal ROIs. The four conditions are represented: happy – to (HT, **black**), happy – away (HA, **red**), disgust – to (DT, **blue**), disgust – away (DA, **green**).

In order to analyze the presence of a priming effect, for each ROI, we conducted a 2 (Target: To, Away) x 2 (Prime: Happiness, Disgust) repeated-measures ANOVAs on the mean voltage of each component of interest. This approach allows to test both the effects of prime-target congruency (suggested by a significant interaction between the prime and target factors), and the possible independent effects of the prime and of the target.

Nc, 350-650 ms, frontal and central ROI

A repeated-measures ANOVA on mean amplitude was performed, with Emotion (happiness, disgust), Action (to, away) and Lateralization (left, midline, right) as factors for frontal and central regions of interest separately.

At **frontal ROI**, a main effect of Lateralization was found, F (1.52,44.21) = 8.05; $p = 0.002$; $\eta^2_p = 0.22$, $\varepsilon = 0.8$. Post-hoc comparisons showed a higher voltage over midline (M_{Fz}= 0.54 µV; SD_{Fz}= 13.5) compared to both left and right electrodes. (M_{F3}= -5.04 µV; SD_{F3}= 12.8; M_{F4}= -4.68 µV; SD_{F4}= 14.5) (all $p_{bonferroni} < 0.002$). No other main effects or interactions were found in the ANOVA (all $p > 0.4$). Nonetheless, when compared to baseline in a one-sample T-Test, none of the conditions resulted to be significant (all $p > 0.08$).

At **central ROI**, no main effects or interactions were found in the ANOVA (all $p > 0.2$). When compared to baseline in a one-sample T-Test, all the conditions resulted to be significantly lower than zero (M_{HT}= -6.17 µV; SD_{HT}= 15.6; M_{DT}= -7.35 µV; SD_{DT}= 15.9; M_{DA}= -7.08 µV; SD_{DA}= 16.3) (all $p < 0.03$), except from the **HA** condition ($p = 0.19$, M_{HA}= -4.36 µV; SD_{HA}= 18.0), probably due to its quicker return to baseline compared to the other conditions, as also suggested by the bigger standard deviations observed.

<u>LSW, 800-1100 ms, all ROI</u>

A repeated-measures ANOVA on mean amplitude was performed, with Emotion (happiness, disgust), Action (to, away) and Lateralization (left, midline, right) as factors, for frontal, central and parietal regions of interest separately.

At **frontal ROI,** a main effect of Action was found (F (1,29) = 23.2, $p < 0.001$, $\eta^2_p = 0.45$). Pairwise comparisons showed that when the action observed was “to”, the mean voltage was lower than when the action was “away” (t (29) = -4.82, $p_{bonferroni} < 0.001$, d =-0.88; M_{to}= -10.60 µV; SD_{to}= 18.3, M_{away}= 4.29 µV; SD_{away}= 20.4) (Figure 10). Moreover, an effect of Lateralization (F (1.64,47.48) = 15.2; $p < 0.001$, $\eta^2_p = 0.34$, ε = 0.86) showed that the voltage over midline was higher than both over left (t (29) = 4.97, $p_{bonferroni} < 0.001$, d =0.8) and right electrodes (t(29) = 4.55, $p_{bonferroni} < 0.001$, d =0.77) (M_{left}= -7.08 µV; SD_{left}= 18.1; M_{rightt}= -6.17 µV; SD_{right}= 19.5; $M_{midline}$= 3.79 µV; $SD_{midline}$= 18.7). No further main effects or interaction were found (all p > 0.4).

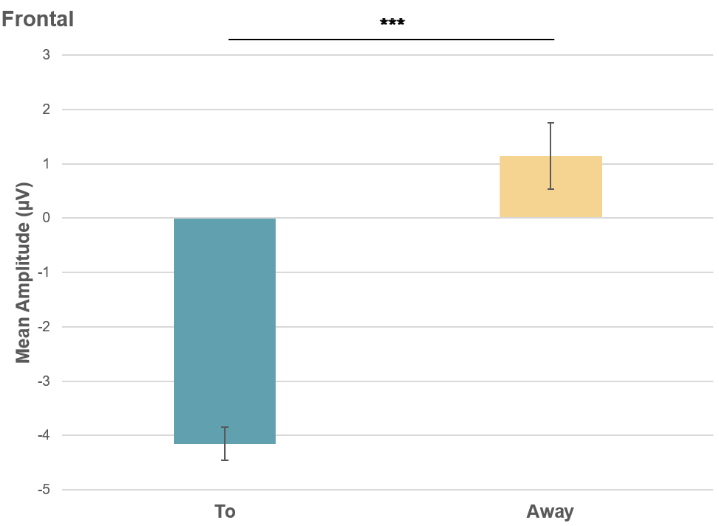

Figure 10. Mean amplitude, the Frontal electrodes for the two conditions (To and Away). Asterisks (***$p < .001$) illustrate that mean voltage in response to the observation of the action “to” (M_{to}= -10.60 µV, SD_{to}= 18.3) was lower than when the action was “away” (M_{away}= 4.29 µV; SD_{away}= 20.4).

At **central ROI,** a main effect of Action was found (F (1,29) = 24.07, $p < 0.001$, $\eta^2_p = 0.45$). Pairwise comparisons showed that when the action observed was “to”, the mean voltage was lower than when the action was “away” (t (29) = -4.91, $p_{bonferroni} < 0.001$, d =-0.9; M_{to}= -12.76 µV; SD_{to}= 15.2, M_{away}= 2.52 µV; SD_{away}= 19.2) (Figure 11). Moreover, an effect of Lateralization (F (2,58) = 3.46, $p = 0.038$; $\eta^2_p = 0.11$) showed that the voltage over midline was higher only than right electrodes (t (29) = 2.58, $p_{bonferroni} = 0.037$, d =0.41) (M_{rightt}= -7.87 µV; SD_{right}= 16.1; $M_{midline}$= -2.94 µV; $SD_{midline}$= 18.0). No further main effects or interaction were found (all p > 0.5).

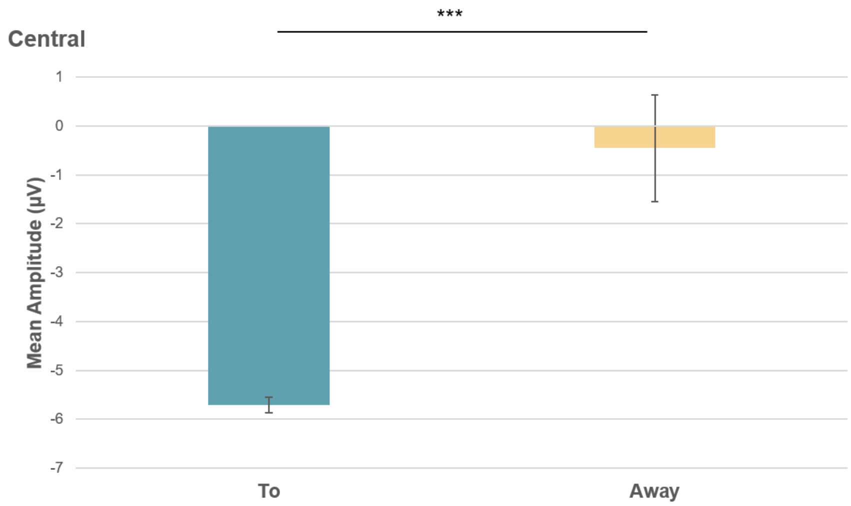

Figure 11. Mean amplitude, the Central electrodes for the two conditions (To and Away). Asterisks (***$p < .001$) illustrate that mean voltage in response to the observation of the action “to” **(**M_{to}= -12.76 µV; SD_{to}= 15.2**)** was lower than when the action was “away” (M_{away}= 2.52 µV; SD_{away}= 19.2).

At **parietal ROI,** a main effect of Action was found (F (1,29) = 14.68, $p < 0.001$, $\eta^2_p = 0.34$). Pairwise comparisons showed that when the action observed was “to”, the mean voltage was lower than when the action was “away” (t(29) = -3.83, $p_{bonferroni} < 0.001$, d = -0.7; M_{to}= -16.37 µV; SD_{to}= 14.3, M_{away}= -3.64 µV; SD_{away}= 17.6) (Figure 12).Moreover, an effect of Lateralization (F (2,58) = 8.43, $p < 0.001$; $\eta^2_p = 0.23$) showed that the voltage over midline was higher only than right electrodes (t(29) = 4.10, $p_{bonferroni} < 0.001$, d =0.78) (M_{rightt}= -6.17 µV; SD_{right}= 13.4; $M_{midline}$= -14.08 µV; $SD_{midline}$= 14.1). Further, a significant interaction between Action and Lateralization (F (2,58) = 7.47, $p = 0.001$, $\eta^2_p = 0.21$) was observed. Pairwise comparisons showed that, when the target action presented was “to”, mean voltage over midline was lower than all other conditions (all

$p < 0.003$) ($M_{midline}$= -23.2 µV; $SD_{midline}$= 16.4, M_{left}= -14.4 µV; SD_{left}= 16.9, M_{rightt}= -11.5 µV; SD_{right}= 13.7). No further main effects or interaction were found (all $p > 0.08$).

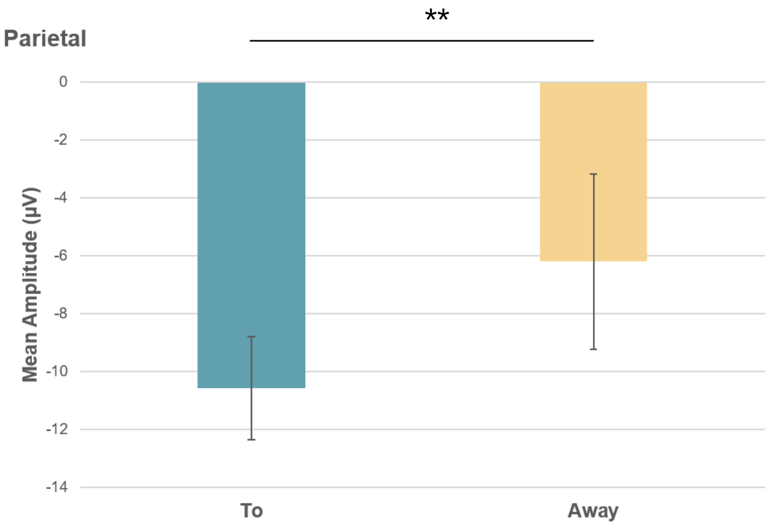

Figure 12. Mean amplitude, the Parietal electrodes for the two conditions (To and Away). Asterisks (**$p < .01$) illustrate that mean voltage in response to the observation of the action "to" (M_{to}= -12.76 µV; SD_{to}= 15.2) was lower than when the action was "away" (M_{away}= 2.52 µV; SD_{away}= 19.2).

Target analysis – Mu-rhythm

Visual inspection of the time-frequency plots suggested the presence of a desynchronization in the 6-9 Hz band within the 100-400 ms time window in central electrodes (Figure 13).

First, a repeated-measures ANOVA on alpha activity with Emotion (Happy, Disgust), Action (To, Away), and Region (Frontal, Central, Parietal and Occipital) as within-subject factors was then performed. The ANOVA yielded a significant main effect of Region (F (1.35, 31.01) = 21.23; $p < .001$, $\eta^2_p = 0.48$, $\varepsilon = 0.34$). Post Hoc comparisons showed that the voltage in the alpha band was lower at the occipital cluster than at frontal (t (23) = -5.13, $p_{bonferroni} < 0.001$, d =-1.05) ($M_{occipital}$= -1.28 µV; $SD_{occipital}$= 1.14; $M_{frontal}$= -0.14 µV; $SD_{frontal}$= 0.35), fronto-central (t (23) = -0.06, $p_{bonferroni} < 0.001$, d =-1.03) ($M_{fronto-central}$= -0.15 µV; $SD_{fronto-central}$= 0.33) central (t (23) = -4.93, $p_{bonferroni} < 0.001$, d =-1.01) ($M_{central}$= -0.18 µV; $SD_{central}$= 0.35) and parietal (t (23) = -4.40, $p_{bonferroni} <$ 0.001, d =-0.9) ($M_{parietal}$= -0.28 µV; $SD_{parietal}$= 0.45) clusters. No further main effect or interaction was found. Therefore, each region of interest was explored separately.

As expected, the ANOVA did not yield significant results neither in frontal nor fronto-central or parietal Regions of interest (all $p > 0.1$).

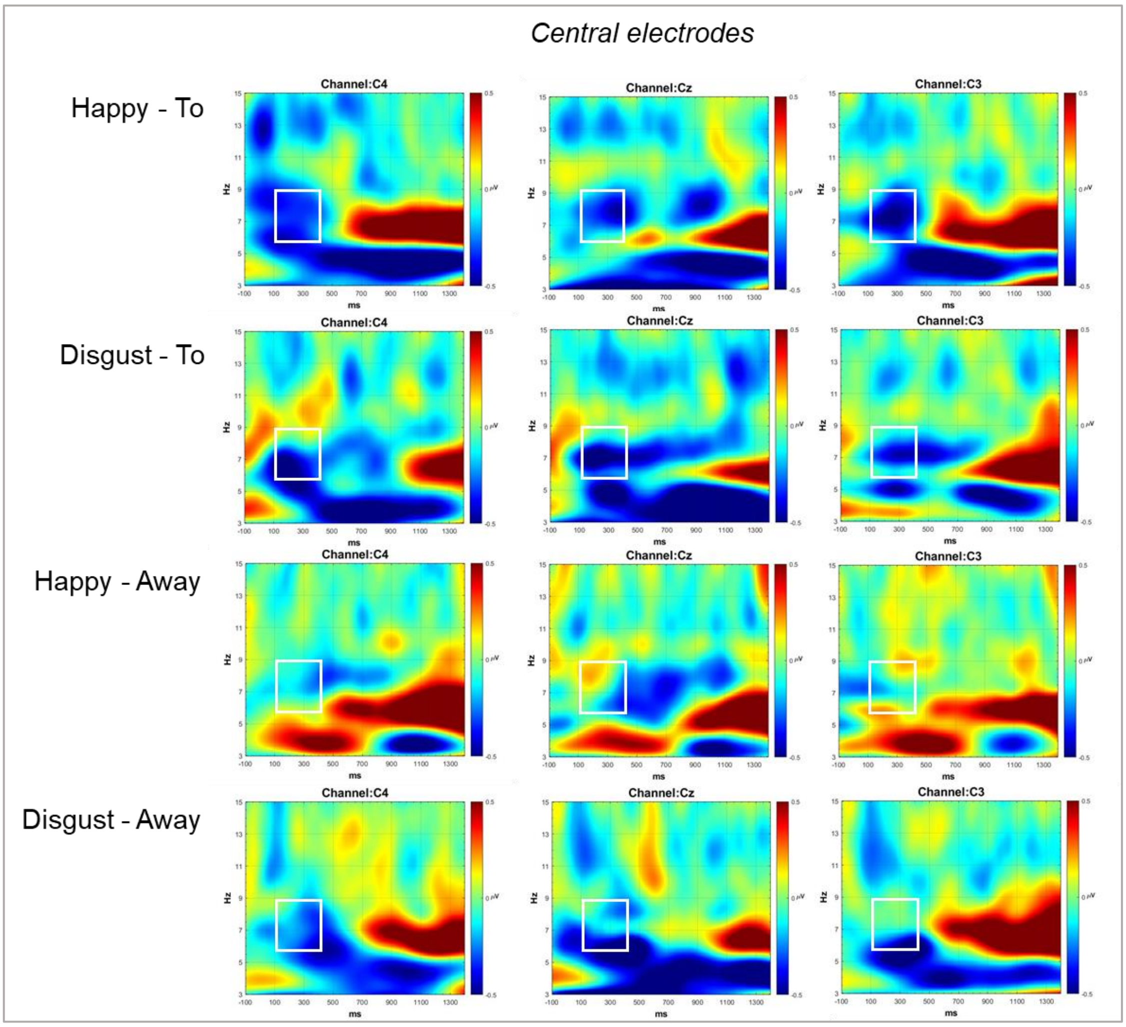

Figure 13. Time frequency plots for the central electrodes (left: C3, middle: Cz, right: C4) for the four conditions. The white rectangles show the selected time window (100-400 ms) for the alpha band analyzed (6-9 Hz).

At central locations, a main effect of Action was found, F (1,23) =4.32, p=0.049*, $\eta_p^2 = 0.16$. The post-hoc comparison showed that, for the action To, the mean voltage was lower than for the Away action (M_{To}= -0.25 µV; SD_{To}= 0.37; M_{Away}= -0.11 µV; SD_{Away}= 0.4), corresponding to a greater mu-rhythm desynchronization (t (23) = -2.08, p=0.049, d= -0.42) (Figure 14).

Finally, at occipital electrodes only a main effect of Lateralization was found, F (1.50, 34.59) =4.04, p=0.037, $\eta_p^2 = 0.15$, ε=0.75. In particular, the electrode over the left recorded a higher voltage than the one over midline (t (46) = 2.84, p = 0.02, d =0.6; M_{left}= -1.04 µV; SD_{left}= 1.05;

$M_{midline}$= -1.52 µV; $SD_{midline}$= 1.35). Crucially, all other main effects or interactions were not significant (all $p > 0.2$). The occipital de-activation did not therefore present differential responses for the different conditions.

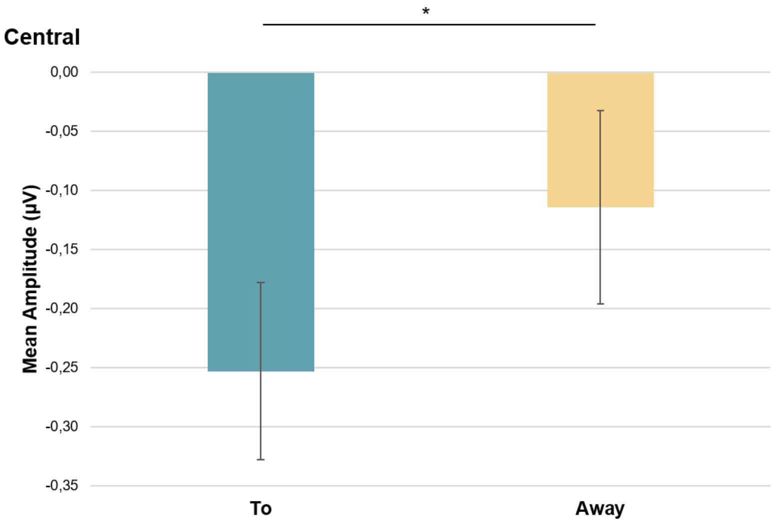

Figure 14. Mean amplitude, the Central electrodes for the two conditions (To and Away). Asterisks (*$p < .05$) illustrate that mean voltage in the 6-9 Hz band of activation was lower in response to the observation of the action "to" (M_{To}= *-0.25 µV;* SD_{To}= *0.37*) than for the action "away" (M_{Away}= *-0.11 µV;* SD_{Away}= *0.4*).

Discussion

From the very beginning of life, infants communicate their states and interact with others. One of the effective ways to interact with others is through emotions. Emotion understanding develops quickly already in the first 10 months of life (Bornstein & Arterberry, 2003; Nelson & Dolgin, 1985; Kotsoni et al., 2001), and their meaning can be conveyed multimodally, through face, vocalization and body movements (Walker, 1982; Soken & Pick, 1999; Hoehl, 2008; Grossmann et al., 2005; Grossmann et al., 2007). By 12-months of life infants not only begin to have a deeper comprehension of emotions but are also ready to actively use it towards interpreting external events (Schupp et al., 2004). The ability of using others' cues towards regulating one's behavior is known as *referencing* (Moses, Baldwin, Rosicky & Tidball, 2001; Vaish & Striano, 2004). Indeed, amongst these cues, emotion play an important role (Repacholi, 2009). We can therefore say that infants, already from the end of their first year of life, start to build expectations on how they should behave based not only on imitation of others' actions, but also on the evaluation of social interactions (Gredebäck & Melinder, 2010; Gredebäck & Daum, 2015; Gergely et al., 2002; Langeloh et al., 2018) and emotional cues (Carver & Vaccaro, 2007). While these assumptions are well supported by behavioral evidence, less is known about the neural correlates of infants' early ability to link others' emotions to their following actions. The present study aimed to help fill this gap in knowledge. We adopted a priming paradigm to investigate how the two actions of holding an object or pushing it away (presented in the target phase) are processed at a neural level, and whether their interpretation is influenced by a preceding emotional information (presented in the priming phase) about that same object.

Firstly, the target phase was then analyzed. An attentional component (Nc, 350-650 ms, at central locations) was observed. All the four conditions evoked a similar attentive response, as no distinction between the two actions nor their interaction with the emotions previously presented (i.e., a congruency effect) was observed. On the other hand, a later component (LSW, 800-1100 ms, at all locations), showed a significant enhanced positivity for the action “away” compared to the action “to”.

Regardless of the object presented the two actions were then processed differently by infants' brains. This is noteworthy, as it means that the actions that others perform on objects are of extreme interest for infants. The fact that a differentiation was not found in the early time window but is present at later latencies, means that the differential processing does not simply depend on a perceptual difference, but rather on their cognitive processing, possibly linked to their social meaning. The heightened positivity for the action “away” could reflect an enhanced processing for the condition that infants find more unusual (Geangu, Quadrelli, Lewis, Cassia & Turati, 2015: Friederici, 2005). Similarly, in an ERP study, this component was observed as more positive in its amplitude for angry and happy prosody than for neutral prosody (Grossman et al., 2005; 2006). Although in that case the investigation domain was emotional prosody, a similar mechanism could be at play in the situation we presented. The action of keeping an object in one's hands and looking at it might be therefore perceived as normal, while pushing the object away could be regarded as odd, and therefore require an enhanced processing. Additionally, this component might be reflecting the update of working memory, and the enhanced positivity following the unexpected action would in this case indicate an elevated attention (Zhang et al., 2010).

The lack of an interaction with emotions presented as a prime does not support the idea that, at 10-months of age, infants use emotional information to interpret following actions. This ability might be emerging between 10 and 12 months (Carver & Vaccaro, 2007). Another possible explanation of the reason why we did not observe a modulation of the response to target actions depending on the emotion observed in the priming phase can be traced back to the social referencing literature. As pointed out in the introduction, one of the aspects that has been considered fundamental to observe social referencing effects is temporal congruity (Moses et al., 2001). Due to the design of our study, this congruity was not preserved, and infants had not only to keep in memory the emotion that they observed, but also link it to a subsequent action. This might have been too complex for 10-month-olds, hence the lack of the expected results. One possible future direction would be to run a study in which temporal synchrony is restored, to test whether this allows infants to detect the emotion – action incongruency (for instance, by providing the auditory information about the emotion while presenting visually the target action).

Furthermore, we analyzed differences in mu-rhythm desynchronization (6-9 Hz in infancy; Marshall & Meltzoff, 2011), often associated with the generation of a prediction about actions (Saby, Marshall & Meltzoff 2012). In line with the ERP results performed on the target phase, we found a reduced mu power in central regions in response to expected actions. This finding suggests that infants' sensorimotor system activates in resonance with the action that they would have themselves performed.

To rule out the possibility that we did not find an effect of emotion because these were not successfully conveyed for the infants, we also analyzed their response to the priming videos. In this case, we observed a frontal and fronto-central negative deflection between 400 and 600 ms, followed by a positive component as described in Grossman et al., 2006. The Nc did not reveal differences in the processing of the two emotions per se, but an interesting result emerged. At frontal locations, only happiness evoked a more negative potential at left and right electrodes compared to midline. A similar result was found in fronto-central electrodes but limited to the left. These data converge towards the idea that infants' brains show a higher degree of specialization for happiness (as we also suggested in the study previously reported in this chapter, 'Contagious smile: the observation of dynamic happy expressions activates sensorimotor areas in 7-month-old infants') than for disgust, although equal attention was apparently allocated to both emotions. The fact that, at an attentional level, both emotions are equally relevant might also be responsible for the lack of interaction with the target actions. One way of seeing the emotions might be that, regardless of their valence, they are a cue towards a relevant situation (Reschke, Walle & Dukes, 2017), leading to the assumption that infants interpret the further exploration of the object as the most sensible outcome. We then observed a later positive waveform (Pc, Grossmann et al., 2006) between 600 and1000 ms at central and parietal electrodes. Voltage for happiness was higher than in the disgust condition. Again, infants showed higher mean amplitude for the condition that was processed the most at a cognitive level. Moreover, at parietal locations happiness was higher in voltage (in particular over midline) compared to disgust. As in the case of the Nc, a greater specialization for information regarding happiness appears also for later latencies.

The results presented could benefit from a functional connectivity analysis, in line with literature concerning neural networks involved in attentional processes (Posner, Sheese, Odludaş, & Tang, 2006). Moreover, as previously mentioned for study 2, the *Permutation Statistics for Connectivity Analysis* (Mamashli, Hämäläinen, Ahveninen, Kenet & Khan, 2019) technique would allow to enhance the ability to identify statistically significant patterns.

To sum up, these results draw a first picture of the domain of emotions and actions coupled neural processing: although both types of information are relevant, 10-month-olds are not yet integrating them in a complex action prediction manner. Further studies will help shed more light on when, and how, this ability emerges.

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Conclusions

> *"We keep moving forward, opening new doors,*
> *and doing new things, because we're curious.*
> *And curiosity keeps leading us down new paths."*
> Walt Disney

Movement, perception, action and the social world are intertwined during human development. Infants and children move to explore their physical and social environment and observe others' movements to know how to act in a goal-directed manner and interact with others. This multi-faceted picture can be inscribed in the embodied perspective, which claims a central role for the body and movement in human cognition. At the very beginning of human life, infants' motor abilities are not developed enough to allow an independent exploration of the environment. These abilities develop quickly in the first years of life, in parallel with other functions, like voluntary control of attention, action and emotion understanding. The process of how infants develop new skills and how they observe others, learn from them, are connected. Babies are in some ways both more limited than us, and yet only through their eyes we can understand how important every single muscle in action can be.

In this thesis we discovered how observed movement, from its most basic form (the kinematic) to the more complex social exchanges, can unveil social messages about others' emotions and how people act during development.

We first discovered how simple animations with a happy and fearful kinematic can be correctly identified by 7- and 10-year-old children, and how fear is recognized faster than happiness by children just as it is by adults. Movement appears to be fundamental for the identification of fear, almost like we were wired to know that a possible response to this emotion is to run away.

We then saw how the perception of dynamic emotional faces increases sensorimotor activation to happy compared to angry faces. Facial expressions are indeed powerful means for emotional communication in everyday life. The differential activation pattern elicited by happy and angry faces indicates us that infants' brains are more specifically activated by happy faces. Negative emotional expressions in the first months of life are still not as deeply encoded, and their comprehension from facial movement might be more complex.

Moving on to the multi-personal aspects of infants' life, we saw how 10-month-olds have the ability to encode specific action – sound outcome associations, being greatly helped by the social dimension of these events. Through the mere observation of others creating new interactive situations with simple movements, infants are developing their predictions on social interactions and learning how to interact themselves.

Finally, infants are also busy learning how to act upon objects. Their environment is filled with things that they never saw before, and everything is new about them. Relying on what others do is a useful tool to adopt successful strategies. Nonetheless, in one last study we discovered that 10-month-olds are drawn to the exploration of unfamiliar objects regardless of a previous happy or disgusted expression of an adult. The emotions, although differentiated, are not yet used as a warning against using a novel object. Infants around this age are curious and want to always know more. In a short time-window (possibly only a couple of months), they will learn that following others' suggestions, even given through emotions, is a more successful strategy.

Movement surrounds us, we live in a world that is never still. From the Earth spinning on its axis, to a baby moving his first steps, from that time we walked the entire day to discover hidden beauties in Paris, to the day we suffered an injury and could not move from our bed. And this past year, where COVID-19 changed radically our lives and we spent most of our days at home. Things like these make us realize how much being able to move around is important for us.

This journey across movement and socio-emotional development answered many of our questions and opened up even more new ones. We will keep moving forward, opening new doors and following our curiosity down to new paths, looking at the world through babies' eyes.