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Three-year-olds' rapid facial electromyographic responses to emotional facial expressions and body postures

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ABSTRACT

Rapid facial reactions (RFRs) to observed emotional expressions are proposed to be involved in a wide array of socioemotional skills, from empathy to social communication. Two of the most persuasive theoretical accounts propose RFRs to rely either on motor resonance mechanisms or on more complex mechanisms involving affective processes. Previous studies demonstrated that presentation of facial and bodily expressions can generate rapid changes in adult and school-age children's muscle activity. However, to date there is little to no evidence to suggest the existence of emotional RFRs from infancy to preschool age. To investigate whether RFRs are driven by motor mimicry or could also be a result of emotional appraisal processes, we recorded facial electromyographic (EMG) activation from the zygomaticus major and frontalis medialis muscles to presentation of static facial and bodily expressions of emotions (i.e., happiness, anger, fear, and neutral) in 3-year-old children. Results showed no specific EMG activation in response to bodily emotion expressions. However, observing others' happy faces led to increased activation of the zygomaticus major and decreased activation of the frontalis medialis, whereas observing others' angry faces elicited the opposite pattern of activation.

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This study suggests that RFRs are the result of complex mechanisms in which both affective processes and motor resonance may play an important role.

Introduction

Seeing the emotional expressions of the people we interact with most often elicits similar expressions in us as observers. One of the most common examples is when we smile in response to seeing other people smile. Our responses can vary from being overt, observable with the naked eye, to being covert and detectable only by using specific electrophysiological measurements (i.e., electromyographic [EMG] measurements) of the muscles involved in generating these expressions. The covert responses can themselves vary from being extended to long periods of activity to being very rapid and subtle, also called rapid facial responses (RFRs). Forms of emotional expression congruency can be recorded in humans from the first months of infancy (e.g., Haviland & Lelwica, 1987), throughout childhood (e.g., Beall, Moody, McIntosh, Hepburn, & Reed, 2008; Deschamps, Coppes, Kenemans, Schutter, & Matthys, 2015; de Wied, van Boxtel, Zaalberg, Goudena, & Matthys, 2006; Oberman, Winkielman, & Ramachandran, 2009), and throughout adulthood (e.g., Bavelas, Black, Lemery, & Mullett, 1986; Hess & Blairy, 2001; Magnée, Stekelenburg, Kemner, & de Gelder, 2007) and have been documented for facial, vocal, and postural modes of emotional expressivity (Hatfield & Cacioppo, 1994). Importantly, these expressivity matching responses have been attributed essential socioemotional functions with relevance for emotional contagion (Hatfield & Cacioppo, 1994), empathy (Decety & Jackson, 2004; De Vignemont & Singer, 2006), social communication (Hess & Bourgeois, 2010), and social coordination through affiliation (Lakin & Chartrand, 2003), to name just a few. Despite a large body of research investigating the mechanisms underlying the variety of these abilities and their functions in adults, we still have limited knowledge about their development (Beall et al., 2008; Jones, 2007). The current study aimed to address this limitation by investigating the development of RFRs to others' emotions in 3-year-old children.

Two main theoretical assumptions have been put forward with regard to the mechanisms underlying RFRs. On the one hand, several researchers regard RFRs as being simple motor responses, triggered by observing others' facial expression, without any direct affective underpinnings, usually labeled as mimicry (Bavelas et al., 1986; Chartrand & Bargh, 1999; Hoffman, 1984; Meltzoff & Moore, 1977). Mimicking others' emotional displays is presumed to rely on perception–action matching mechanisms, whereby perceiving the pattern of motor behavior specific for expressing different emotions activates the same motor response in the observer (De Waal, 2009; Hatfield & Cacioppo, 1994; Lipps, 1907; Meltzoff, 2007). At the neural level, the mirror neuron system is hypothesized to be involved in eliciting these motor resonance responses (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003). Analogous to the neurons first described in the ventral premotor cortex and the inferior parietal lobule of the macaque brain (Ferrari, Gallese, Rizzolatti, & Fogassi, 2003; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Umiltà et al., 2001), the human mirror neuron system (including the pars opercularis of the inferior frontal gyrus, the ventral premotor cortex, and the anterior inferior parietal lobule) has been found to be responsive when adults both perform and observe simple goal-directed motor acts (e.g., Buccino et al., 2001; Buccino, Binkofski, & Riggio, 2004; Iacoboni & Dapretto, 2006; Iacoboni et al., 1999; Rizzolatti & Craighero, 2004), including emotional facial expressions (Lee, Dolan, & Critchley, 2008; Lee, Josephs, Dolan, & Critchley, 2006; Pfeifer, Iacoboni, Mazziotta, & Dapretto, 2008). According to this theoretical account, once elicited, RFRs can lead to a change in the affective state of the observer through associations with previously experienced emotions, generating emotional contagion (Cappella, 1993; Hoffman, 1984; Laird, Alibozak, & Davainis, 1994; Lipps, 1907).

In support of this view, it has been shown that adults' vocal (Hatfield & Hsee, 1995), facial (Davis, Senghas, Brandt, & Ochsner, 2010; Manstead, 1988; Matsumoto, 1987), and postural (Duclos et al., 1989; Stepper & Strack, 1993) posing of emotional displays influences their experienced emotional state as well as their evaluation of the emotional stimuli (Strack, Martin, & Stepper, 1988).

However, the change in the affective state is not mandatory in all social situations. Emotional mimicry has also been proposed to serve communicative functions and to be guided by cultural norms (Hess & Bourgeois, 2010; Lakin & Chartrand, 2003). Smiling in response to others' smiles can signal acknowledgment of affiliative intentions as well as the desire to affiliate and might not necessarily lead to a change in the observers' affective state (Hess & Blairy, 2001; Hess, Blairy, & Kleck, 2000; Hess & Bourgeois, 2010; Knutson, 1996).

In contrast to the automatic mimicry view of RFRs to others' emotions, more recent theoretical perspectives suggest that these responses may be the result of more complex mechanisms involving a combination of motor, affective, and cognitive processes (Beall et al., 2008; Bourgeois & Hess, 2008; Hess, Philippot, & Blairy, 1998; Jones, 2007; Moody & McIntosh, 2006; Moody & McIntosh, 2011; Moody, McIntosh, Mann, & Weisser, 2007). The emotions of other people are usually highly salient for us, conveying important information for our social success and survival. Processing such emotional information can elicit a change in our affective states as observers, which is further expressed through face, body posture, and prosody. According to this view, the change in affective state and the corresponding RFRs will not necessarily be congruent with the observed facial expression but rather congruent with the emotional interpretation and the affective state of the observer. Moreover, any emotional expression modality and any emotional information can elicit such responses.

One particularly strong argument in favor of this latter perspective comes from studies investigating RFRs to expressions of anger. Expressions of anger are perceived by children and adults as signaling threat and elicit increased allocation of attention and fast activation of the limbic system, similar to perceiving expressions of fear (Kret, Pichon, Grèzes, & de Gelder, 2011; Monk, 2008; Nelson & Nugent, 1990; Pichon, de Gelder, & Grèzes, 2009). Feeling fear in response to others' anger has a potentially adaptive value because it can facilitate flight in front of danger (LeDoux, 2000; Moody et al., 2007). It has been shown that adults in a high state of fear respond very fast to observing pictures of angry faces, with an increased activation of the facial muscles involved in expressing fear (Moody et al., 2007). This suggests that RFRs are more congruent with the felt emotion than with the observed expression. Adult RFRs specific to fear are also elicited by images depicting environmental threat, such as snakes (Dimberg, 1997), and by seeing bodily expressions of fear (Magnée, Stekelenburg et al., 2007; Tamietto & de Gelder, 2008). This indicates that, at least in certain situations, these responses are less likely to be the result of motor mimicry because the corresponding motor model is not present (Moody & McIntosh, 2006; Tamietto et al., 2009).

RFRs relying on emotion-specific programs can also be automated to a certain degree. When adults are presented with masked emotional faces and body postures that they are not able to consciously see, they nevertheless show RFRs consistent with the emotional valence of the stimuli (Tamietto & de Gelder, 2008). Even adults who are unable to consciously perceive visual information, due to unilateral destruction of the visual cortex, show RFRs congruent with the emotional valence of the facial and bodily expressions of emotions (Tamietto et al., 2009). In contrast, RFRs that mimic the observed emotional facial expressions tend to be associated with increased allocation of attention, as indexed by changes in the electrical cortical activity (Achaibou, Pourtois, Schwartz, & Vuilleumier, 2008), similar to other instances of non-emotional motor resonance (Chong, Cunnington, Williams, & Mattingley, 2009). The modulation of RFRs by early cognitive processes may explain the dissociation in the chain of processes elicited by perceiving others' emotions, activating either perception–action matching mechanisms or affect-related processes. Functional magnetic resonance imaging (fMRI) studies show that both emotion-related circuitries and cortical networks typically associated with perception–action matching mechanisms are activated during imitation and passive viewing of facial expressions of emotions. However, due to the poor spatial resolution of the method, they cannot disambiguate which mechanism has primacy (Carr et al., 2003; Lee et al., 2006, 2008; Pfeifer et al., 2008).

Although it is widely agreed that at least beginning at 20 months of age children systematically reproduce, in a spontaneous manner, various non-emotional motor gestures observed in adults (Flynn & Whiten, 2008; Hopper, Flynn, Wood, & Whiten, 2010; Jones, 2007), a less clear picture has emerged so far with regard to their facial responses to others' expressions of emotions. Some clues are provided by the research investigating children's abilities to empathize (see Eisenberg, 2000, for a recent review). In most of these studies, changes in children's facial, vocal, and postural expressivity as a result of observing others' emotions are typically measured in order to establish the presence of empathic responses. The evidence converges in showing that children respond to others' affect, most often negative affect, with congruent emotional states (Decety & Svetlova, 2012; Eisenberg, 2000).

Few studies have specifically investigated children's RFRs to others' emotional displays by using EMG recordings of the facial muscles. One of the most important findings resulting from these studies is that children between 6 and 12 years of age show changes in their facial muscle activity in response to observing a variety of adult and child emotional facial expressions (i.e., happiness, anger, sadness, fear, and disgust) presented in either a static or dynamic way (Beall et al., 2008; Deschamps et al., 2015; de Wied et al., 2006; Oberman et al., 2009). Most of these studies assume that children's RFRs are the result of motor matching mechanisms (Deschamps et al., 2015; de Wied et al., 2006; Oberman et al., 2009) due to the selective activation of those facial muscles involved in the observed facial expression. Children's passive viewing of emotional facial expressions also leads to a small increase in the hemodynamic response of the cortical areas typically associated with the mirror neurons system (Pfeifer et al., 2008). One study, however, suggests that children's RFRs may also involve affective processes. Beall and colleagues (2008) presented 7- to 12-year-olds with static adult facial displays of happiness, anger, and fear while the activity of the muscles specifically involved in expressing each of these emotions (i.e., zygomaticus major, corrugator supercilii, and medial frontalis, respectively) was recorded using electromyography. Similar to the other studies, increased activity in the zygomaticus major, the smiling muscle, was recorded when children looked at happy faces. Unlike in the other developmental studies, but similar to some adult investigations (Moody et al., 2007; Magnée, De Gelder, Van Engeland, & Kemner, 2007), seeing angry faces elicited selective increased activation of the medial frontalis muscle typically involved in raising the eyebrows while expressing fear (Darwin, 2002; Ekman, 1979). Therefore, children seem to display a facial expression that matches their affective state, in this case fear, in response to anger as a potential threat (Monk, 2008; Nelson & Nugent, 1990).

Several possible explanations could account for these discrepant results. Most of the studies in which children react with RFRs matching the perceived expression use active tasks in which the participants are asked to specifically pay attention to the emotional expression, to identify it, and to verbally label it (de Wied et al., 2006; Oberman et al., 2009). This increased attention to the emotional expressions may have influenced subsequent processing, activating those mechanisms involved in mimicry, as suggested by the adult findings (Achaibou et al., 2008). Indeed, when adults and children specifically focus their attention on mimicking a facial expression, the activation of the cortical areas associated with the mirror neuron system is higher than during passive viewing (Pfeifer et al., 2008). One solution that could help to further reduce the ambiguity regarding the mechanisms involved in children's RFRs is to present children with emotional stimuli containing cues about the motor acts required for mimicking the associated expression (i.e., faces) and emotional stimuli in which such information is absent (e.g., emotional body postures, emotional prosody). If affect processes are primarily responsible for observing the RFRs, then one would expect that they are similarly present for both types of stimuli (De Gelder, Snyder, Greve, Gerard, & Hadjikhani, 2004; Magnée, De Gelder et al., 2007; Magnée, Stekelenburg et al., 2007; Tamietto & de Gelder, 2008).

The current study aimed to advance our understanding of RFR development in two respects. First, we investigated whether such responses are present during childhood earlier than previously shown. Although evidence suggests that at least from 2 years of age children can spontaneously reproduce the non-emotional motor gestures observed in others (e.g., Jones, 2007), most research on emotional RFRs has focused on children over 6 years of age. Our study aimed to reduce this gap by testing 3-year-olds' RFRs using EMG measurements of facial muscle activity. Second, the current study investigated whether 3-year-olds' pattern of RFRs is consistent solely with motor mimicry interpretation or could also be regarded as a result of emotional appraisal processes. To help delineate between the two processes, we presented children with static images of both faces and body postures displaying happy, angry, fearful, and neutral emotional expressions. By 3 years of age, children recognize and label body expressions of emotions with the same accuracy as for facial expressions (Nelson & Russell, 2011), suggesting good abilities to process the emotional information expressed in this way. Recording the selective activation of the facial muscle representative for a certain emotional expression (i.e., zygomaticus major for happiness, corrugator supercilii for anger, and frontalis medialis for fear) in response to both faces and body postures would be more consistent with an emotional processing interpretation (Magnée, Stekelenburg et al., 2007; Tamietto & de Gelder, 2008). This idea would be further supported by finding that observing displays of anger elicit the selective activation of the frontalis medialis, the facial muscle specific for expressing fear (Beall et al., 2008).

Method

Participants

A total of 22 healthy 3-year-old children (10 girls; mean age = 40.42 months, range = 36.50–47.57) were included in the final analysis. An additional 19 children were tested but then discharged from the final sample because they refused to watch the stimuli ($n = 7$), moved too much during trial presentation ($n = 8$), or did not complete the minimum number of trials required for data analysis ($n = 4$). The protocol was carried out in accordance with the ethical standards of the Declaration of Helsinki and approved by the ethics committee of the university. Parents gave written informed consent for their children to participate in the study.

Stimuli and procedure

Participants were presented with color photographs of human female *faces* and *bodies* displaying happy (HA), angry (AN), fearful (FE), and neutral (NE) expressions on a 24-inch LCD monitor at a distance of approximately 80 cm. Face stimuli were selected from the Radboud Faces Database (RaFD; Langner et al., 2010), whereas body stimuli were extracted from the Bodily Expressive Action Stimulus Test database (BEAST; De Gelder & Van den Stock, 2011). Both face and body stimuli were screened and selected by three adult raters for their emotional valence. To ensure that the processing of the emotional information expressed through body postures was not influenced by the facial expression,

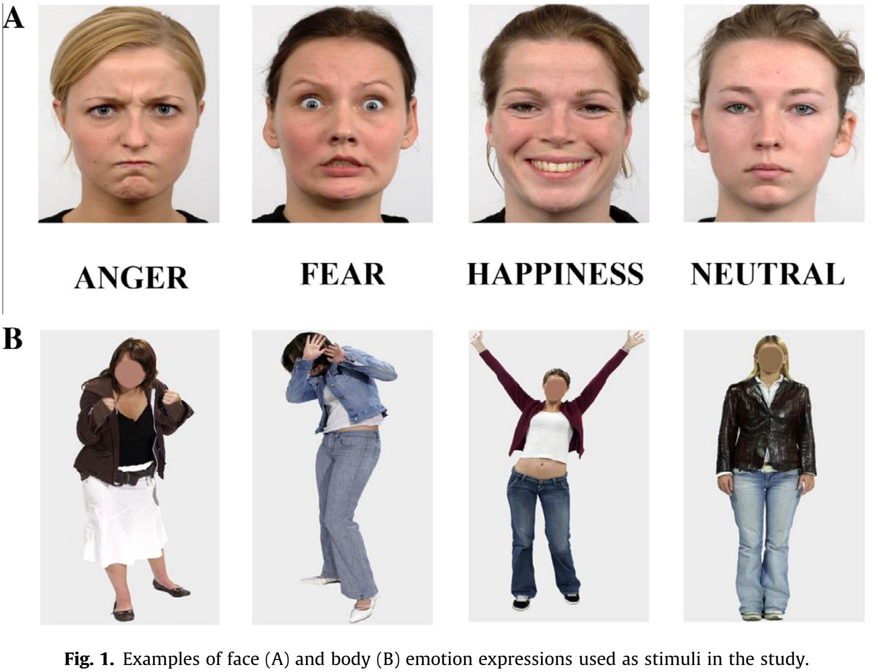

Fig. 1. Examples of face (A) and body (B) emotion expressions used as stimuli in the study.

all faces on the body stimuli were masked with an opaque patch (Fig. 1). Each stimulus was presented at the center of the screen on a gray background for 500 ms and was preceded by an interstimulus interval of 2000 ms consisting of a gray screen with a central fixation cross, similar to previous studies using this paradigm (Oberman et al., 2009). In a completely within-participants design, face and body stimuli were presented in alternating blocks. Each block consisted of 20 randomly presented stimuli (five for each emotional expression), with the only constraint being that stimuli displaying the same emotion could not occur more than twice consecutively. The order of presentation was counterbalanced across participants, so that half of them started the experiment with the body condition and the other half started with the face condition.

On completing informed consent procedures, participants' faces were cleaned and scrubbed with NuPrep Gel to ensure good quality signal recording from the EMG electrodes. Children sat on a chair in a dimly lit, audiometric, and electrically shielded cabin. An experimenter was present throughout the entire procedure, so that participants' movements were minimized and their interest and attention were maintained. Children were instructed to relax, to not move or talk, and to watch the pictures on the screen. No other instruction was given to the participants. For the children to become familiarized with the procedure and to ensure that they understood the instructions, each session started with eight practice trials in which an equal number of faces and bodies were displayed. Total duration of the task was approximately 15 min, and at the end of the session participants received a small reward.

EMG recordings and data reduction

Electromyography was used to record the levels of muscle activation for the zygomaticus major (raises the cheek), the medial frontalis (raises the brow), and the corrugator supercilii (knits brow). These muscles were chosen based on previous studies showing that their activation is a reliable marker for facial expressions of happiness (zygomaticus major), anger (corrugator supercilii), and fear (frontalis medialis) (Cacioppo, Petty, Losch, & Kim, 1986; Ekman & Friesen, 1976; Frois-Wittman, 1930). A D360 Digitimer electromyograph was used to continuously record the EMG signal from the selected muscles using bipolar montages, following previously established guidelines (Tassinary, Cacioppo, & Vanman, 2000). Ambu Neuroline 700 surface adhesive 4-mm Ag–AgCl electrodes for pediatric use were placed on the child's face at locations corresponding to each muscle. The electrodes were positioned longitudinal to the muscle, with an inter-electrode distance of 10 mm between their centers. Electrodes were positioned on the left side of the face to obtain maximal reactions (Fridlund & Cacioppo, 1986). The reference electrode was positioned just below the hairline approximately 3 cm above the nasion. Impedance was kept between 5 and 10 kΩ using a conductive EMG gel (Viasys Electrolyte Gel). The EMG signal was amplified online by a factor of 1000 and recorded at a sampling rate of 1 kHz with a 10- to 1000-Hz bandpass filter. The EMG signal was filtered offline (150 Hz; high pass: 30 Hz), and further rectified for analysis using Spike2 software (Cambridge Electronic Design, Cambridge, UK). Because of difficulties and excessive noise recorded from the corrugator supercilii muscle, data acquired from this electrode site were excluded from further analysis. One consequence of the lack of data from this muscle is that it will make it difficult to draw conclusions regarding the presence of RFRs specific to anger. Nevertheless, considering our prediction of fear RFRs to the emotional stimuli expressing anger, intact recordings of the frontalis medialis will allow us meaningful interpretations of the results in this respect (Beall et al., 2008).

Children's looking time toward the stimuli was coded offline, and trials in which children looked at the stimuli for less than 70% of their duration or were moving were discarded. To avoid any spurious effect produced by participants' movements while watching the stimuli, trials were also discarded whenever signal noise and motion artifacts contaminated the EMG recordings. Only children with at least four trials per emotion/condition were included in the statistical analyses. Across participants, the mean number of trials contributing to the statistical analyses was 13.02 (HA: 13.09; AN: 12.77; FE: 13.59; NE: 12.64) per emotion in the face condition and 12.98 (HA: 13.41; AN: 12.82; FE: 13.23; NE: 12.45) per emotion in the body condition. A similar number of trials contributed to the final analysis for each condition, $F(3, 63) = 2.016$, $p > .12$.

Average amplitude values were calculated for each 100-ms interval from 500 ms pre-stimulus onset to 1500 ms post-stimulus. To reduce the impact of extreme values and standardize the observed activation, we transformed raw data into *Z* scores within participants and muscle sites. Next, each 100-ms interval post-stimulus onset was baseline corrected by subtracting the average amplitude of the 500-ms pre-stimulus interval from the average amplitude of each 100-ms post-stimulus onset interval. Finally, trials of the same emotion and condition were averaged to obtain one value for each 100-ms interval of every trial type. Previous studies with children using a similar paradigm have shown that the facial muscles usually begin to show differentiated activation in response to facial expressions of emotions after 500 ms from stimulus onset, reaching the peak at around 1000 ms in the case of longer stimulus presentations (Beall et al., 2008; Oberman et al., 2009), which is also consistent with adult studies (Dimberg, 1982; Dimberg & Peterson, 2000; Moody et al., 2007). Visual inspection of the data in the current study suggested a similar pattern, with the recorded muscles showing differentiated activation between 800 and 1300 ms post-stimulus onset. The mean amplitude values for this time window were further analyzed using a 2 (Condition: bodies or faces) × 4 (Emotion: happy, angry, fearful, or neutral) × 2 (Muscle: zygomaticus major or medial frontalis) repeated measures analysis of variance (ANOVA). All statistical tests were conducted at the .05 level of significance (two-tailed), and paired sample *t*-tests were corrected for multiple comparisons using the Holm–Bonferroni stepwise procedure. Furthermore, to confirm that the EMG activity of a specific muscle changed in response to a certain emotional stimulus, each significant Emotion × Muscle interaction was followed up by a comparison of the non-baseline-corrected EMG data of each condition during the 800- to 1300-ms post-stimulus onset with that recorded during the 500-ms pre-stimulus baseline when a fixation cross was displayed. For this purpose, we used paired *t*-tests at the .05 level of significance (two-tailed).

Results

Table 1 shows the mean activation (with standard deviations) for the zygomaticus and frontalis muscles across conditions. The results of the 2 (Condition: face stimuli or body stimuli) × 4 (Emotional Expression: happy, angry, fearful, or neutral) × 2 (Muscle: zygomaticus major or frontalis medialis) repeated measures ANOVA show a significant interaction among condition, emotional expression, and muscle, $F(3, 60) = 6.008$, $p = .001$, $\eta^2 = .231$. No other significant main effects or interactions were found ($p > .291$). To unpack this interaction, 4 (Emotional Expression: happy, angry, fearful, or neutral) × 2 (Muscle: zygomaticus major or frontalis medialis) repeated measures ANOVAs were performed separately for each condition.

Face stimuli

A significant interaction between emotional expression and muscle emerged, $F(3, 60) = 5.310$, $p = .003$, $\eta^2 = .210$, suggesting a selective activation of the recorded muscles for specific emotional expressions. Post hoc pairwise comparisons revealed that observing facial expressions of happiness elicited increased activation of the zygomaticus major ($M = .090$, $SD = .160$) compared with observing

Table 1
Means (and standard deviations) of EMG activation recorded from the zygomaticus and frontalis muscles in response to facial and bodily expressions of emotion in the 800- to 1300-ms time window.

		Zygomaticus (*Z* scores) *M* (*SD*)	Frontalis (*Z* scores) *M* (*SD*)
Anger	Face	−.075 (.147)	.060 (.122)
	Body	.059 (.208)	−.073 (.219)
Happiness	Face	.090 (.160)	−.057 (.112)
	Body	.013 (.106)	.045 (.123)
Fear	Face	−.038 (.158)	−.024 (.141)
	Body	−.022 (.196)	−.006 (.172)
Neutral	Face	.024 (.163)	.038 (.144)
	Body	−.023 (.234)	.022 (.128)

angry faces (M = –.075, SD = .147), t(21) = 3.452, p = .026. In contrast, observing facial expressions of anger led to an increased activation of the frontalis medialis (M = .060, SD = .122) compared with observing happy faces (M = −.056, SD = .112), t(21) = 3.396, p = .036 (Fig. 2). The use of standardized Z scores also allowed us to compare the level of activation between muscles. The analysis of the difference in activation for both zygomaticus major and frontalis medialis within emotion expression further supports the results of selective activation by showing that observing facial expressions of happiness led to activation of the muscle responsible for smiling (zygomaticus major, M = .090, SD = .160) and deactivation of the muscle that raises the eyebrows (frontalis medialis, M = −.056, SD = .112), t(21) = 3.696, p = .014, whereas observing angry faces led to activation of the frontalis medialis (M = .060, SD = .122) and deactivation of the zygomaticus major (M = −.075, SD = .147), t(21) = 3.387, p = .036. When compared with the baseline, observing happy facial expressions elicited an increased activation of the zygomaticus major, t(21) = 2.392, p = .026, whereas observing angry faces led to a decrease in the activation of the same muscle, t(21) = −2.501, p = .021. In contrast, observing happy faces led to a decrease in the activity of the frontalis muscle from the baseline levels, t(21) = −2.688, p = .014, whereas the same muscle tended to show increased activation in response to angry faces when compared with the baseline, although it was marginally significant, t(21) = 1.947, p = .066. No other significant differences emerged.

Body stimuli

The analysis of the average muscle activation recorded in response to observing body postures did not show a significant interaction between the emotional expression and the type of muscle, Emotional Expression × Muscle, $F(3, 60) = 2.355$, p = .100, $\eta^2 = .105$ (Fig. 3). Similar levels of activation of both zygomaticus major and frontalis medialis were recorded in response to all types of body postures (p > .960).

Discussion

The aim of our study was to investigate whether 3-year-olds show RFRs to others' expressions of emotions and to explore the mechanisms underlying these responses. Toward this aim, we presented children with static images of faces and bodies displaying happy, fearful, angry, and emotionally neutral expressions. RFRs were recorded using EMG activation from the zygomaticus major, the muscle involved in pulling the corners of the mouth into a smile, typically associated with expressing happiness, and from the frontalis medialis, the muscle that raises the eyebrows, typically involved in expressing fear.

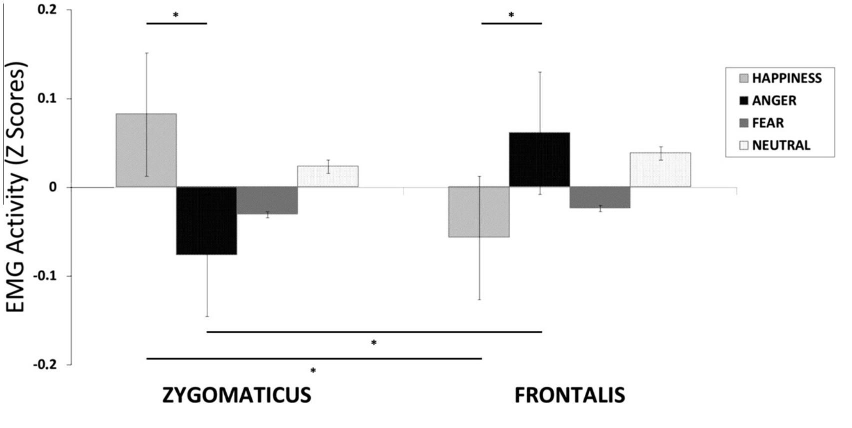

Fig. 2. EMG activation recorded from the zygomaticus (left) and frontalis (right) muscles in response to facial expressions of emotion in the 800- to 1300-ms time window. Error bars represent standard errors. The '⁎' indicates the comparisons significant at p = .05.

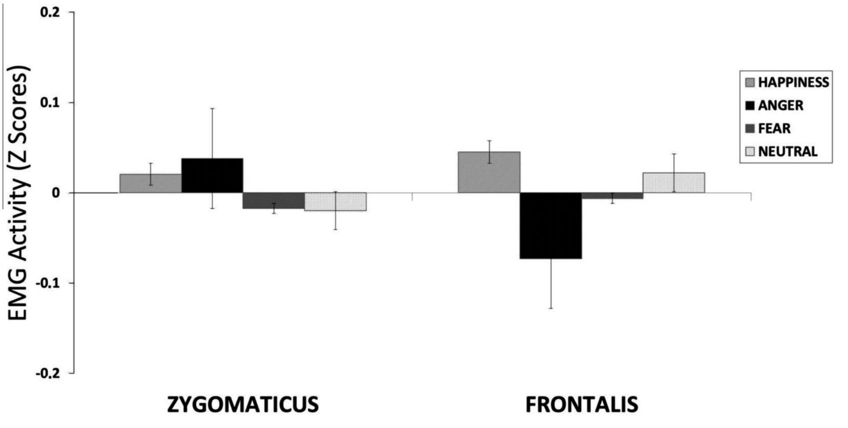

Fig. 3. EMG activation recorded from the zygomaticus (left) and frontalis (right) muscles in response to body expressions of emotion in the 800- to 1300-ms time window. Error bars represent standard errors.

Convergent with previous studies with older children (Beall et al., 2008) and adults (Moody et al., 2007), we have shown for the first time that 3-year-old children manifest selective RFRs, as measured by electromyography, to static facial expressions of happiness and anger. More specifically, observing others' happy faces led to increased activation of the zygomaticus major and decreased activation of the frontalis medialis. Observing angry faces triggered an opposite pattern of activation. These findings were supported by the analysis of the EMG responses both when conditions were directly compared with each other and when each condition was compared with the baseline.

RFRs to angry facial expressions suggest that affective processes may also be involved and, thus, do not rely solely on perception–action matching mechanisms (Beall et al., 2008; Bourgeois & Hess, 2008; Hess et al., 1998; Jones, 2007; Moody & McIntosh, 2006; Moody & McIntosh, 2011; Moody et al., 2007). Based on the responses to happy facial expressions alone, such an interpretation would be hazardous given that both types of processes would result in similar responses. Seeing someone smiling could be processed as a cue for pleasant social interaction leading to a happy response in the observer, usually expressed through smiling. Mimicking the observed smile in order to acknowledge others' affiliative intentions would also lead to this response (Hess & Blairy, 2001; Hess et al., 2000; Hess & Bourgeois, 2010; Knutson, 1996). However, the fact that angry faces led to a change in facial muscle activation specific to fear is more in line with interpreting RFRs as involving the emotional interpretation of the stimuli (Beall et al., 2008; Moody et al., 2007). An angry face with the eye gaze directed at the perceiver is usually regarded as threatening and potentially elicits fear (Öhman, 2005). The fact that we were not able to provide information about the response of the corrugator muscle to static angry faces may be regarded as limiting our conclusions. However, the activation of the frontalis medialis, with or without the associated activity of the corrugator, is specific for expressing fear, not anger (Boxtel, 2010; Ekman & Friesen, 1978). Further investigations where measures of emotional arousal (e.g., heart rate, pupil dilation, galvanic skin response) are recorded simultaneously with facial electromyography from all three muscles could help to elucidate whether 3-year-olds' RFRs to others' emotional facial expressions are associated with a change in the affective state. This association may also depend on the extent to which different children respond emotionally to socioemotional events and the efficiency with which they regulate their emotions given that the temperamental characteristics recorded during the first years of life largely explain the variability in empathy development (Van der Mark, van IJzendoorn, and Bakermans-Kranenburg, 2002; Young, Fox, & Zahn-Waxler, 1999).

Neither the emotionally neutral faces nor the fearful faces elicited selective activation of the recorded facial muscles. The fact that in our study static fearful faces did not elicit selective RFRs in 3-year-old children is in line with Beall and colleagues' (2008) findings for 7- to 12-year-old children and Moody and colleagues' (2007) findings for adults. However, they are in contrast to those of

Deschamps and colleagues (2015) and Oberman and colleagues (2009). Facial expressions of fear are typically regarded as cues for threat (Adams, Gordon, Baird, Ambady, & Kleck, 2003; Pessoa, Japee, & Ungerleider, 2005) that capture attention and elicit fear (Öhman, 2005; Vuilleumier, 2002). One possible explanation for the lack of selective RFRs in our study could be that 3-year-olds' abilities to process fearful facial expressions are not sufficiently mature. In terms of processing the specific facial features, humans are able to discriminate fearful expressions from other emotionally positive and negative facial expressions both visually and at the neural level as early as 5 to 7 months after birth (Hoehl & Striano, 2008; Schwartz, Izard, & Ansul, 1985). Notwithstanding infants' sophisticated abilities to process others' emotional expressions, the literatures converge to suggest that it takes many years before children reach adults' level of accuracy and speed in recognizing facial expressions. In particular, children's sensitivity to fearful expressions continues to improve until 10 years of age (Herba & Phillips, 2004; Gao & Maurer, 2009; Gao & Maurer, 2010). Moreover, it is possible that 3-year-olds experience fewer negative emotional expressions than positive ones, and in particular they may encounter fewer instances during everyday life of other people manifesting fearful facial expressions than happy and even angry ones (Gao & Maurer, 2010; Grossman, Striano, & Federici, 2007). Our finding that the frontalis muscle tends to show less change from baseline in response to angry faces than the response of the zygomaticus muscle in response to happy faces could be regarded as indirectly supporting the idea that a differential amount of experience with certain emotional expressions may have an impact on children's RFRs. The most experienced emotional expressions could more easily trigger RFRs than the less experienced ones.

Another different interpretation for the lack of RFRs for fearful facial expressions might suggest the involvement of affect mechanisms. Beyond infancy, more complex knowledge about emotions, including fear, emerges. For example, the ability to verbally label emotional expressions is manifest more systematically for happiness and anger at around 3 years of age, whereas for fear it is more toward 5 years of age (Widen & Russell, 2003). Knowledge about the events that could potentially cause fear, although present to a certain extent by 2 years of age, continues to improve beyond 3 years of age (Denham & Couchoud, 1990; Mondloch, Horner, & Mian, 2013). Thus, one possibility could be that insufficient affect knowledge about fear impairs 3-year-old RFRs to these emotional expressions. However, this explanation is less likely to account for the same findings in Beall and colleagues (2008) because by 7 to 12 years of age affect knowledge is advanced. Future studies in which measures of affect knowledge are included could help to test this hypothesis.

The discrepant results in RFRs to fear may also be due to a difference in the saliency of the fearful expressions as cues for threat used in the current and previous studies. Oberman and colleagues (2009) asked children to verbally label and categorize the observed emotional expressions, whereas Deschamps and colleagues (2015) presented dynamic stimuli. These procedural aspects may have modulated children's processing of emotional expressions. In our study, similarly to Beall and colleagues (2008), we asked children to watch static facial expressions of fear with gaze directed toward the observer without any further instructions. It is possible that in passive tasks using static stimuli that provide impoverished emotional information, the interpretation of fearful facial expressions as cues for threat is more dependent on certain features of the face or of the environment pointing to the source of threat such as eye gaze (Fox, Mathews, Calder, & Yiend, 2007; Hoehl & Striano, 2008; Hoehl & Striano, 2010; Neath, Nilsen, Gittsovich, & Itier, 2013). Fearful faces with eye gaze directed toward a specific aspect of the environment more clearly point to the specific source of threat, and it is more meaningful than a fearful face with eye gaze oriented toward the observer. This typically influences participants' attentiveness and behavior related to that object starting from infancy (Hoehl & Striano, 2010) and continuing throughout childhood and adulthood (Neath et al., 2013). Thus, it is possible that the static fearful stimuli used in our study and in Beall and colleagues (2008) were not sufficiently informative with respect to the potential threat. Future studies in which the orientation of eye gaze in fearful and angry faces is specifically manipulated, as well as the use of both static and dynamic stimuli, could greatly contribute to understanding the underlying mechanisms of RFRs to emotional faces in children.

As for the bodily expressions of emotions, we found that observing human bodies with happy, angry, fearful, and emotionally neutral postures resulted in non-selective RFRs. Taken in isolation from the pattern of EMG responses to facial expressions of emotions, these findings would suggest that 3-

year-old children's RFRs could be the result of perception–action matching mechanisms (Bavelas et al., 1986; Chartrand & Bargh, 1999; Hoffman, 1984; Meltzoff & Moore, 1977). Nevertheless, Because RFRs to emotional facial expressions did not fully follow the pattern of muscle activation expected in case of mimicry (i.e., zygomaticus major for happiness and frontalis medialis for fear), this explanation is less likely to be the case. In adults, emotion-specific facial muscle activity has been recorded in response to both faces and bodies expressing happiness and fear (Magnée, De Gelder et al., 2007; Tamietto & de Gelder, 2008). Thus, what could explain the difference in RFRs to static emotional body postures between adults and 3-year-old children? Although only few studies have investigated the development of processing emotional information expressed in body postures, they converge in showing that already by 6 to 8 months after birth, infants discriminate visually and at the neural level between positive and negative emotional body postures (Zieber, Kangas, Hock, & Bhatt, 2014; Missana, Rajhans, Atkinson, & Grossmann, 2014). Thus, it is less likely that the lack of emotion-specific RFRs in 3-year-olds is due to an inability to tell apart different emotional body postures. In addition, 3-year-olds correctly label emotional expressions for both bodies and faces (Nelson & Russell, 2011), suggesting that this ability might not necessarily account for the RFRs to body postures. One task in which 3-year-olds perform differently for facial expressions and body postures is the ability to relate emotional expressions observed in others with the events potentially causing them (Mondloch et al., 2013). Although 3-year-olds are able to correctly associate an emotional facial expression of a person with the events most likely causing the associated affective state, they fail to do so for emotional body postures. This may be due to the difference in emotional information that the body postures communicate (Ekman, 1965). The ability to interpret such information may develop at a different pace than faces, potentially explaining the lack of emotionally specific RFRs to emotional body postures in 3-year-olds. In our current study, we did not include any measure of affect knowledge to assess whether 3-year-olds discriminate, label, and understand the meaning of different means of emotional expressivity. Further studies in which other emotional expression modalities than those included in this study are used (i.e., emotional prosody) together with measures of affect knowledge could help us to understand whether the lack of selective RFRs for emotional expressions other than faces reflects the presence of perception–action mechanisms, affective processes, or a combination of both.

In sum, the findings of our study provide valuable insight into 3-year-old children's facial responses to others' emotions, particularly when displayed in static images, and show that EMG recordings can be a viable tool of investigation for this age group. The reported results speak in favor of RFRs as the result of complex mechanisms in which affective processes may play an important role. These findings add to a growing body of research on the development of complex social and emotional abilities such as empathy (Decety, 2015; Decety & Svetlova, 2012; Geangu, 2015; Geangu, Hauf, Bhardwaj, & Bentz, 2011) and social understanding (Carpendale & Lewis, 2006; Meltzoff, 2007). It would be particularly interesting to explore whether RFRs to others' emotions are related to children's abilities to share the emotional experiences of people around them or whether they contribute to how well children understand their own and others' emotions. In light of recent research showing that electromyography is a valid tool to be used even with infants (Natale et al., 2014; Turati et al., 2013), the current findings open an important possibility for addressing long-standing questions about infants' facial responses to others' emotional expressions (Field et al., 1983; Geangu et al., 2011; Haviland & Lelwica, 1987; Kaitz, Meschulach-Sarfaty, Auerbach, & Eidelman, 1988; Ray & Heyes, 2011).

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