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Rapid facial reactions to emotional facial expressions in typically developing children and children with autism spectrum disorder

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ABSTRACT

Typical adults mimic facial expressions within 1000 ms, but adults with autism spectrum disorder (ASD) do not. These rapid facial reactions (RFRs) are associated with the development of social–emotional abilities. Such interpersonal matching may be caused by motor mirroring or emotional responses. Using facial electromyography (EMG), this study evaluated mechanisms underlying RFRs during childhood and examined possible impairment in children with ASD. Experiment 1 found RFRs to happy and angry faces (not fear faces) in 15 typically developing children from 7 to 12 years of age. RFRs of fear (not anger) in response to angry faces indicated an emotional mechanism. In 11 children (8–13 years of age) with ASD, Experiment 2 found undifferentiated RFRs to fear expressions and no consistent RFRs to happy or angry faces. However, as children with ASD aged, matching RFRs to happy faces increased significantly, suggesting the development of processes underlying matching RFRs during this period in ASD.

Introduction

Seeing a smiling face makes most people smile, and seeing an angry face can make them scowl (Bush, Barr, McHugo, & Lanzetta, 1989; Dimberg, 1982; McIntosh, 2006; McIntosh, Druckman, &

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Zajonc, 1994). The questions of why and how they do so have become increasingly important as our understanding of the role of interpersonal matching in development and social processes has expanded (Rogers & Williams, 2006). There is a wide variety of interpersonal matching behaviors, all of which include an observer engaging in behaviors similar to those of a model (Moody & McIntosh, 2006; Williams, Whiten, & Singh, 2004). Some of the more complex behaviors, such as imitation, likely build on components of the most simple behaviors, such as automatic matching of emotional facial expressions (Moody & McIntosh, 2006; Rogers, 1999). The current experiments examine these simple automatic facial responses in children. They are the first to demonstrate that facial electromyography (EMG) can be used to study these subtle and rapid responses in typically developing children and children with autism spectrum disorder (ASD). More important, Experiment 1 examines the mechanisms responsible for these rapid reactions, and Experiment 2 investigates these responses in children with ASD. Experiment 2 points toward the functional significance of these reactions and considers the development of matching in ASD.

Rapid facial reactions

Emotional facial mimicry is one type of rapid facial reaction (RFR). RFRs are commonly observed in adults after exposure to facial expressions. They occur very rapidly—within 1000 ms—and are often very subtle (Cacioppo, Petty, Losch, & Kim, 1986; Moody, McIntosh, Mann, & Weisser, 2007). Due to their speed and subtlety, investigators typically use EMG with surface electrodes placed over facial muscles to examine their occurrence. When an adult sees a picture of a happy facial expression, the muscles responsible for raising the cheek in a smile (zygomaticus major) typically show an increased level of activity; when an adult sees an angry expression, the muscles responsible for knitting the brows in a scowl (corrugator supercilii) may have greater activity (Dimberg, 1982, 1988; Moody et al., 2007). These RFRs can occur even when people are exposed to facial expressions so quickly that they cannot consciously recognize the expressions (Dimberg, Thunberg, & Elmehed, 2000; Rotteveel, de Groot, Geutskens, & Phaf, 2001).

RFRs that match the observed expressions are associated with several important social and emotional abilities. In particular, matching of facial expressions has been theorized to be critical for social functioning, emotional contagion, empathy, and understanding of another person's state of mind (Decéty & Chaminade, 2003; Hatfield, Cacioppo, & Rapson, 1993, 1994; Iacoboni, 2005; Lakin & Chartrand, 2003; McIntosh, 2006; Scambler, Hepburn, Rutherford, Wehner, & Rogers, 2007; Sonnby-Borgstroem, 2002). In terms of evolution, expression matching may be adaptive because it helps humans to communicate and foster relationships (Lakin, Jefferis, Cheng, & Chartrand, 2003). Moreover, matching behaviors in general have important developmental functions such as facilitating social and emotional connectivity and understanding (Bavelas, Beavin-Black, Lemery, & Mullett, 1987; Masur & Rodemaker, 1999). Indeed, early RFRs may be important precursors to later, more complex imitative processes often studied in ASD. Therefore, it is important to understand RFRs and the role they play in interpersonal development and imitation.

Although the presence of RFRs to emotional stimuli is well documented in adults (Dimberg, 1982, 1988; McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006), there has been less work examining facial responses to facial expressions in children. Some studies suggest that newborns and infants less than 1 month of age match simple facial movements (Meltzoff & Moore, 1977) and emotional expressions (Field, Woodson, Greenberg, & Cohen, 1982), although the evidence is inconsistent (Anisfeld, 1996; Kaitz, Meschulach-Sarfaty, Auerbach, & Eidelman, 1988). With development, there is more evidence of matching behaviors. Jones (2007) found that matching motor behaviors were not observed at 6 months of age but developed through the 2nd year of life. In addition, contagious yawning does not appear before 5 years of age, and the probability of occurrence continues to increase throughout childhood (Anderson & Meno, 2003). Evidence during toddlerhood for emotional responsiveness to others' emotion displays was provided by Scambler and colleagues (2007). They studied emotional responsiveness to live adult displays of joy, fear, disgust, and pain among 2-year-olds with ASD, children with other developmental delays, and typically developing children. The children's facial and behavioral responses were videotaped and coded for coordination in the valence of the emotion between child and experimenter. All groups showed some level of emotional respon-

sivity, with children with ASD showing less. Facial responses to others' emotions have also been demonstrated in preschoolers and second graders. Judges rated expressions on children's faces to be highly congruent with the emotions displayed by children being viewed in films (Eisenberg et al., 1988).

Despite the evidence indicating early matching and increases in matching with development, an important ambiguity remains. What causes the observed matching display? Among infants, the most consistently observed behavior (tongue protrusion) may be due not to motor matching or imitation but instead to arousal or exploration caused by the adult facial display (Anisfeld et al., 2001; Jones, 1996). Moreover, there is also evidence for emotional contagion among infants. Newborns cry at the sound of other newborns crying (Martin & Clark, 1982; Simner, 1971). At 10 to 14 months of age, infants orient to others' distress, and some exhibit distress crying (Zahn-Waxler & Radke-Yarrow, 1982). Thus, any observed congruence of emotional facial responses may be due to shared emotion, not simple behavior matching. This analysis underscores the importance of careful examination of the mechanisms causing observed facial responses to others' facial expressions. Among infants and older children, behaviors that match observed expressions might not be due to motor mimicry or simple imitation; instead, they might be due to other processes such as arousal, exploration, and emotional contagion.

The specific mechanisms responsible for RFRs have only recently begun to be investigated (Moody et al., 2007). Indeed, recent investigations of the development of imitation during infancy suggest that the "origins of imitation" and the mechanisms producing mimicry and other matching behaviors "are almost entirely unknown and waiting to be described and explained" (Jones, 2007, p. 598). The current study advances the exploration of this category of behaviors by using EMG to examine mechanisms of children's RFRs to others' emotional facial expressions. This study builds on previous work that used visual coding of expressions (e.g., Eisenberg et al., 1988; Scambler et al., 2007). By using EMG, which detects rapid and subtle expression changes, the current study facilitates examination of the initial responses to others' facial displays and can track these changes over time. This allows us to establish the characteristics of rapid facial responses and explore the mechanisms that drive them. No work has used EMG to document whether the rapid reactions to emotional expressions seen in adults are evident in children or what mechanisms are responsible for RFRs from middle childhood through early adolescence. Such information is critical for understanding the development of RFRs and for understanding processes of typical and atypical social–emotional engagement during this phase of development.

The current study specifically examines RFRs between 7 and 12 years of age because the development of the mechanisms underlying the response may be especially important during this time. This period is important in the development of perceiving and understanding other people's emotions. During this time, children increasingly take others' perspectives (Selman, 1976; Selman & Byrne, 1974), increasingly respond empathically (Hoffman, 2000), and focus on peer interactions (Higgins & Parsons, 1983). The enhanced social focus of emotions in this age group suggests that mechanisms not available earlier in development may influence responses to others' emotions. Examining the nature of RFRs during this age period is important because RFRs may play a role in fundamental interpersonal processes (Reed & McIntosh, 2008) and have significant functional consequences if disrupted (Moody & McIntosh, 2006).

Possible underlying mechanisms of RFRs

Although the presence of simple matching during infancy and of intentional imitation during toddlerhood suggests that matching behaviors are established by 7 years of age, their existence leaves open the question of the specific nature or mechanism of any matching observed. For example, when a 10-year-old sees a happy face, it seems likely (although not yet demonstrated) that he or she will automatically respond with happy RFRs. The underlying mechanism of such rapid responses has often been described as motor mimicry, but here we investigate whether there is another underlying mechanism. In fact, there are two theorized reasons or underlying mechanisms for these rapid responses: motor mimicry (the 10-year-old automatically matches the observed expression via a nonemotional process) and an emotional response (the observed smile evokes a happy emotion, so he or she displays a smile) (Moody et al., 2007).

RFRs are often described as a direct, nonaffective motor matching reaction (Chartrand & Bargh, 1999), typically termed *mimicry*. This direct perception–action neural link may be viewed as bypassing emotional systems and being mediated by the mirror–neuron system (Buccino, Binkofski, & Riggio, 2004; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005; Williams, Whiten, Suddendorf, & Perrett, 2001). Such motor matching is one method through which people come to share others' emotions (Bavelas et al., 1987; Hatfield et al., 1993, 1994; McIntosh et al., 1994).

The second mechanism that may be involved in producing matching facial displays is an affective one. In contrast to motor mimicry generating emotion through facial feedback processes (McIntosh, 1996), a person's initial response to the face may be an affective response. If the observer "catches" the emotion of the face, then a matching emotional display would be produced (Cacioppo, Martzke, Petty, & Tassinary, 1988; Dimberg, 1997; Winkielman & Cacioppo, 2001). Emotional responses to others' emotions are a plausible cause for matching RFRs because such emotional responsiveness occurs quite early in development (for a review, see Hatfield et al., 1994).

Although emotional responses are often a catching or matching of the other's emotion, the affective mechanisms might not always produce a matching response. An observer may respond with a nonmatching emotion. If this response occurred, then the RFRs would be complementary instead of matching. In support of the latter hypothesis that RFRs are tied to an emotional state stemming from the stimuli, recent work has found that RFRs do not always directly match the observed facial expression. Sometimes adults react to an angry face not by drawing their brows together in a matching scowl but instead by raising their eyebrows and expressing fear (Moody et al., 2007). This work underscores the point that the matching behaviors seen may be more than motor mimetic; they may reflect emotional responses that can be complementary to the observed emotional face. Because RFRs are likely critical to social–emotional development, it is important to understand what underlying processes are reflected by RFRs and whether they are the same in younger samples as in adults.

The current study

In Experiment 1, we examined RFRs to emotional facial expressions in typically developing children from 7 to 12 years of age. First, we investigated whether children show RFRs to such stimuli. The occurrence of RFRs in adults is robust; however, although we predict their existence during this age period, RFRs have not been documented or described in children of any age. If RFRs are building blocks to more complex imitation and other social–emotional skills evident in children and adults, then RFRs should be evident during childhood.

Second, we investigated possible mechanisms responsible for RFRs. Specifically, we investigated whether the patterns of RFRs in children indicate that responses to the emotional facial expressions are consistent solely with motor mimicry or show emotional influences on the responses. To help delineate the two processes, we focused on RFRs to angry expressions because muscle activation representing fear to an angry face (i.e., increased medial frontalis activation) would suggest an emotional response. Finding emotional responses would support the interpretation that emotional influences (and not merely motor matching) on RFRs occur during this age period. Matching responses (increased corrugator activation) would be consistent with both motor matching and emotional responses.

Experiment 2 builds on Experiment 1 by examining the existence, patterns, and mechanisms of RFRs in a sample of children with ASD. Examining RFRs in children with social–emotional deficits can help to uncover the extent to which RFRs are associated with typical development and social–emotional functioning. Together, the experiments involving typically developing children and children with ASD provide an examination of the presence of RFRs in development and the mechanisms underlying them.

Experiment 1

In Experiment 1, we examined whether typically developing children from 7 to 12 years of age produce specific RFRs in response to emotionally expressive photographs of faces. Children viewed faces

exhibiting happy, angry, and fear expressions. We recorded continuous EMG activity from three facial muscles: corrugator supercilii (knits brows), medial frontalis (raises inner eyebrows), and zygomaticus major (raises cheeks).

In adults, specific RFRs occur in response to the emotional faces observed. In response to angry expressions, there is increased corrugator muscle (matching an angry expression) or frontalis muscle (indicating a fear response); in response to fear expressions, there appears to be increased activity over the medial portion of the frontalis muscles; and in response to happy expressions, there is increased activity over the zygomaticus muscles (Darwin, 1872/1998; Ekman & Friesen, 1976; Frois-Wittman, 1930; Lundqvist & Dimberg, 1995; McIntosh, 2006; McIntosh et al., 2006; Moody et al., 2007; Smith, 1989). RFRs to happy and angry expressions measured by EMG methodology have been demonstrated consistently. However, enhanced frontalis activation in response to fear faces as measured by EMG (Moody et al., 2007) is less well established. If children exhibit RFRs that are consistent with adult RFR patterns, then the activity of the three facial muscles would differ from each other within each facial expression.

Furthermore, Experiment 1 tested whether there are emotional influences or components to the RFRs in children through an examination of the RFRs for angry expressions. Both emotional and motor matching responses to smiling and fearful faces should generate congruent muscle activation; for example, on seeing a smile, both matching the motor action and expressing happiness generate raised cheek movement. However, responses to anger expressions appear different if the responses include an emotional (i.e., fear) response to the angry expression (Moody et al., 2007). When presented with someone who is angry and scowling, a scowling response could be due to motor processes, emotional processes, or both. However, if fear responses (enhanced frontalis activation) to anger faces are observed, then this suggests that emotional processes are involved in RFRs in children. In this experiment, we considered which muscles respond to anger faces to determine whether emotional responses or merely motor matching are evident.

Method

Participants

A total of 15 typically developing children (10 boys and 5 girls) from 7 to 12 years of age with a mean age of nearly 9 years (M = 8 years 10 months, SD = 1 year 9 months, Mdn = 9 years 0 months) were recruited from a database at the University of Colorado at Denver, School of Medicine. It includes typically developing children participating in a longitudinal study of the developing phenotype of autism and children from the Denver metro area in a general developmental participant pool not affiliated with that study. No other descriptive information about participants was collected. Parents received $15 for their children's participation, and children received a prize for their participation. In addition, 2 other participants were tested but were not included in the final sample because 1 failed to complete the experimental session (7-year-old girl) and 1 did not follow instructions (6-year-old girl who giggled, was distracted, and failed to follow directions).

Stimuli

Stimuli were digitized gray-scale and color photographs of human faces displaying happy, angry, and fear expressions. To enhance ecological validity (color images) and generalizability (multiple ethnicities and expressions), facial expression stimuli from three stimulus sets were selected: Pictures of Facial Affect (Ekman & Friesen, 1976), NimStim (Tottenham, Borscheid, Ellertsen, Marcus, & Nelson, 2002), and Japanese and Caucasian Facial Expressions of Emotion (JACFEE) (Biehl, Matsumoto, Ekman, & Hearn, 1997). Emotion, ethnicities, and coloring of the faces selected per set were as follows: Pictures of Facial Affect, happy and angry gray-scale Caucasian faces; JACFEE, angry and fear color Caucasian and Asian faces; NimStim, happy, angry, and fear color Caucasian, Asian, and African American faces. All images had been validated and used in previous studies examining reactions to emotional faces (e.g., Matsumoto & Ekman, 1989; McIntosh et al., 2006). In other studies, these images had a mean reliability of emotion identification of 91% (range = 66–100%). The three emotions chosen allowed an examination of one positive emotion (happy) and two distinct negative emotions (anger and fear). Moreover, the inclusion of angry faces allowed an examination of whether RFRs included

emotional responses. All happy facial expressions included corners of the mouth pulled back in a smile, all anger expressions included furrowed brows, and all fear expressions included raised eyebrows.

Face images were cropped using an oval frame (12 cm width × 16 cm height) that allowed facial features to be visible but excluded hair and ears. Other distracting features, such as hair strands and odd coloration, were also removed from the images. A total of 46 stimuli were used. An equal number of male and female faces were selected for each emotion. The ethnicities of the faces were as follows: Caucasian, 18; African American, 5; and Japanese, 7.

Procedure

The experimental procedure went as follows. Participants were greeted by the experimenter and were shown the equipment and data collection rooms. They were shown the electrodes and were allowed to handle one. Participants were then shown a picture of a boy's face with stars on it to indicate where the electrodes would be placed on their own faces. The steps of the experiments were presented to participants pictorially. First, their faces would be cleaned using rubbing alcohol and scrubbing gel. Second, electrodes would be placed on their faces using sticky tape. Third, they would sit still without touching their faces and watch the computer screen. Fourth, when they finished, they would pick a prize. They were told that we were interested in how children respond to images, specifically faces. After viewing these steps, parents signed a consent form and participants signed an assent form approved by the institutional review boards of the University of Denver and the University of Colorado at Denver, School of Medicine.

After consent procedures were completed, participants' faces were cleaned with rubbing alcohol and gently abraded with NuPrep Gel, and then electrodes were applied. Participants were allowed to play Game Boy video games during this process. Once the electrodes were in place and impedances of the electrodes were checked, participants were positioned in a chair approximately 57 cm in front of the monitor with their legs in front of them and their hands to their sides. The room was dimly lit. Participants were asked not to touch their faces. For each block of trials, participants were instructed to watch the screen and keep their eyes on the presented faces. They were also told that they could look away from the screen once the face disappeared but that they needed to look at the screen again as soon as they heard the beep.

The start of each trial began with an orientation beep (50 ms). At the start of the beep and for 450 ms after the beep, the screen was blank. Baseline muscle activity levels were established during this period. Following the blank screen, an image of a face appeared for 3000 ms, followed by a random intertrial interval of either 5000 or 7000 ms during which time the screen was blank. Trials were blocked by emotion and image type (color or gray scale). There were five blocks. Two blocks consisted of 8 randomized trials of gray-scale faces: one block of happy expressions and one block of angry expressions. Three blocks consisted of 10 randomized color faces: one block each of angry, happy, and fear expressions. The two gray-scale blocks were presented first and in random order by emotion across participants. The three color blocks were then presented in random order by emotion across participants. Participants completed 46 trials and were videotaped throughout the session to assess visual attention to stimulus presentation. After the first two blocks of trials were finished, participants were permitted to take a break. The complete experimental session took approximately 40 min.

Measures

For facial muscle movement, EMG was used to record levels of muscle activity over the corrugator supercilii (knits brow), the medial frontalis (raises inner eyebrow), and the zygomaticus major (raises cheek). Activity over the corrugator muscle has been shown to be a marker of negative emotions such as anger (Cacioppo et al., 1986); therefore, we used this as a marker of anger expressions. Activity over the medial portion of the frontalis has been associated with fear (Darwin, 1872/1998; Ekman & Friesen, 1976; Frois-Wittman, 1930; Smith, 1989) because when one is afraid, the brow often raises. We used activity here to measure fear expressions. Activity over the zygomaticus muscle has been shown to be a marker of positive emotions such as happiness (Cacioppo et al., 1986). We used activity here to measure happy expressions.

Standard EMG site preparation and electrode placement procedures were followed (Tassinary, Cacioppo, & Geen, 1989). Electrodes were 4-mm Ag-AgCl cup-style electrodes (Med Associates). Muscle activity was continuously recorded using a SynAmps model 5083 electroencephalograph amplifier (NeuroScan Labs). Activity over each muscle group was recorded using two electrodes placed approximately 1.25 cm apart from center to center, roughly parallel to the length of the muscle. Activity over each muscle was continuously recorded at a sampling rate of 2000 Hz with a 10- to 500-Hz bandpass filter and a 60-Hz notch filter. The EMG signals were immediately amplified at the headbox by a factor of 150 and again by the main amplifier by a factor of 500.

To analyze EMG, each continuous file was inspected visually for noise and artifacts (Dimberg, Hansson, & Thunberg, 1998; Winkielman & Cacioppo, 2001). The waveform around each stimulus presentation was visually inspected to look for artifacts and anomalous waveforms. Sweeps that contained clearly anomalous waveforms were dropped from the analyses. An average of 7% of the sweeps were dropped per individual, with no more than 17% of the sweeps being dropped for any single participant. Videotape inspection was used to eliminate trials in which participants were not looking at the screen or had delays in attending to the face images.

EMG data were used to calculate facial responses to the stimuli. The prestimulus window was the 500 ms before the onset of the orienting stimulus during which there was a blank screen. The poststimulus onset muscle activity was averaged in 100-ms chunks. For data analyses, six poststimulus windows from 500 to 1100 ms poststimulus onset were used. The period beginning 500 ms after stimulus onset typically shows the clearest facial muscle reaction (Dimberg, 1982; Dimberg & Petterson, 2000; Moody et al., 2007). Examining changes in muscle activity across these windows allows us to determine whether the pattern of muscle activity changes across time. Either a main effect of muscle or an interaction between muscle and time would indicate the presence of RFRs.

Data were smoothed and rectified, and the integral under the curve for each time window was calculated using CNS Analysis Suite software (version 5.51, The Ohio State University Social Neuroscience Laboratory). The integral values were then $\log_{10}$ transformed. This is a standard procedure in this lab (e.g., McIntosh et al., 2006) and other labs (e.g., Winkielman & Cacioppo, 2001) to reduce the impact of extreme values. These values were then standardized within participant and within muscle so that meaningful comparisons could be made across muscles and participants. Then the prestimulus value was subtracted from the poststimulus onset activity to measure the level of activity caused by viewing each facial stimulus (i.e., to calculate the change from baseline). Finally, mean levels of activity for corrugator, frontalis, and zygomaticus muscles for each type of stimulus face were computed.

Results and discussion

Data were examined for movement artifacts, failure to look at stimulus during presentation, and participant interference with the electrodes. Based on videotape analysis, only four trials were excluded from data analyses due to a failure to look at stimulus during presentation. Furthermore, children tolerated the facial electrodes throughout the experiment and did not dislodge any of them. Finally, the muscle responses were sufficient to analyze the data using standard procedures.

We evaluated whether children produced RFRs associated with specific face muscle and emotion combinations. We conducted three repeated measures analyses of variance (ANOVAs)—one for each emotion (happy, fear, or angry)—using averaged poststimulus muscle activity data: 3 (Muscle: corrugator supercilii, frontalis, or zygomaticus major) $\times$ 6 (Time: 500, 600, 700, 800, 900, or 1000 ms poststimulus onset). For each of these ANOVAs, a main effect for muscle would indicate that different muscles are activated by viewing a specific facial emotion overall. Furthermore, a Muscle $\times$ Time interaction would indicate that differential muscle activation has a specific time course of activation. Examining timing and muscle activation together is important to help determine whether muscle activation varies over time. RFRs may be fleeting, and various mechanisms hypothesized to account for them may occur at different points in time (e.g., motor matching may occur more rapidly than emotional responses). Detailed EMG recordings, as used here, have not been used with children; thus, it is not known when the responses will occur.

For responses to happy facial expressions, we found a significant Muscle $\times$ Time interaction, $F(10, 140) = 2.94$, $p < .01$, partial $\eta^2 = .17$. At 500 ms, the zygomaticus muscle activity is differentiated from

other muscle activity and remains more active over time (Fig. 1A). The zygomaticus muscle is associated with happy facial expressions because it pulls up the corners of the mouth to create a smile. This interaction is consistent with adult RFR data and suggests that children produce robust RFRs to happy faces. This finding is consistent with both motor matching and emotional responses. Neither the main effect of muscle, $F(2, 28) = 2.06$, *ns,* partial $\eta^2 = .13$, nor the main effect of time, $F(5, 70) = 1.54$, *ns,* partial $\eta^2 = .10$, was significant.

For fear facial expressions, neither the Muscle × Time interaction, $F(10, 140) = 1.82$, *ns,* partial $\eta^2 = .08$, nor the main effect of muscle, $F(2, 28) < 1$, *ns,* partial $\eta^2 = .04$, was significant. There was a significant effect of time, $F(5, 70) = 2.95$, $p < .05$, partial $\eta^2 = .17$); Fig. 1B suggests that this is due to average muscle activity decreasing over time. As displayed in Fig. 1B, children did not produce differential RFRs to fear faces.

Because EMG-assessed RFRs to fear faces have been examined less than RFRs to happy and angry expressions, it is not clear whether this absence of frontalis activation to fear faces differs from adult

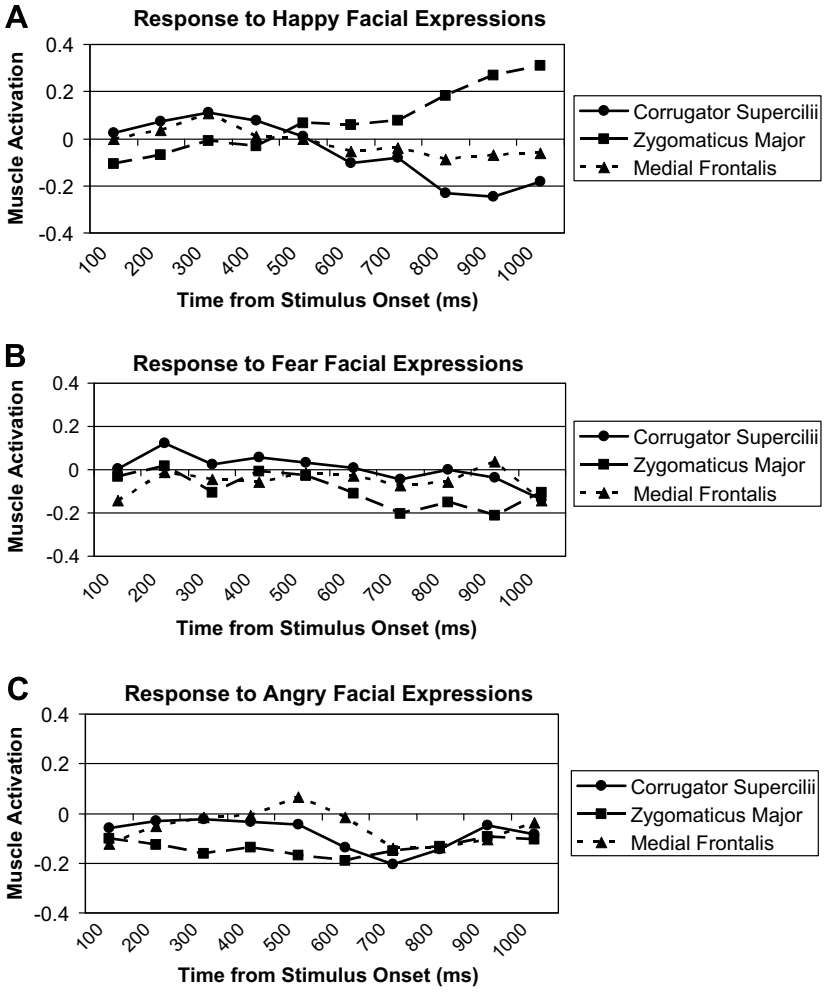

Fig. 1. EMG responses in Experiment 1 with typically developing children. These are averaged, baseline-corrected responses for each 100-ms window following onset of happy emotion faces (A), fear faces (B), and angry faces (C) for all three muscles. Muscle activation differs significantly over time for happy and angry expressions.

responses. Further work should examine RFRs to fear expressions in both children and adults to determine the nature of any such responses.

For angry facial expressions, we found a significant Muscle × Time interaction, $F(10, 140) = 2.14$, $p < .05$, partial $\eta^2 = .13$. At 500 ms, the medial frontalis muscle had greater activation than did the other facial muscles (Fig. 1C). The main effect of muscle was not significant, $F(2, 28) < 1$, *ns,* partial $\eta^2 = .01$, but time was marginally significant, $F(5, 70) = 2.07$, $p = .08$, partial $\eta^2 = .13$. These results indicate that children produced RFRs to angry faces, and the muscle most activated is consistent with a facial fear response (frontalis). Thus, this pattern suggests that an emotional response played a defining role in the RFRs. A pure motor or muscle match would have been indicated by increased corrugator activity, which is used to produce an angry facial expression. The relatively enhanced activation of the medial frontalis, a nonmatching muscle, may reflect a reaction to the facial stimulus in the form of raising the brow in fear. This emotional response of fear to angry faces is consistent with findings in adults (Lundqvist & Dimberg, 1995; Moody et al., 2007).

We conducted exploratory analyses to examine whether the degree to which children matched observed facial expressions is related to age. For each expression (happy, angry, or fear), we computed a score indicating how congruent each child's facial responses were to the face the child was viewing. Specifically, for the 500- to 1000-ms poststimulus period, we subtracted incongruent muscle activation from congruent muscle activation. For example, happy expressions involve contraction of the zygomaticus muscle, not the frontalis and corrugator muscles. Thus, we subtracted average frontalis and corrugator activation from zygomaticus activation for each participant. Larger positive difference scores indicated greater matching RFRs (e.g., greater smiling muscle activation than nonsmiling muscle activation after viewing a smiling face). Pearson correlation coefficients between age and degree of matching RFRs were not significant: happy faces, $r(13) = .02$, *ns;* angry faces, $r(13) = .22$, *ns;* and fear faces, $r(13) = .01$, *ns* (critical value of p set at .02 to protect against family-wise inflation of alpha).

In sum, Experiment 1 demonstrated that typically developing children from 7 to 12 years of age produce reliable RFRs to angry and happy face stimuli as measured by EMG. The fear RFRs for angry faces further indicate that participants' responses were more consistent with an emotional response mechanism given that they are not a direct match but instead reflect a complementary emotional response. The emotional nature of the stimulus—its meaning—appears to elicit the rapid responses. This is consistent with results among adults (Moody et al., 2007). RFRs appear to be present during this age period, and an emotional response mechanism seems to underlie RFRs to angry faces. Therefore, RFRs are a candidate for being a component for imitative and social–emotional abilities.

In addition, we found no association between age and degree of matching RFRs. Although power was low in this sample size (with $N = 15$, power was $\leqslant .10$), none of the correlations showed more than a low effect size. The highest was recorded with angry at $r = .22$. Thus, it appears that by this age period, the tendency to respond rapidly to facial expressions is not affected by continued development. Consistent with non-EGM work demonstrating expression and emotion matching in very young children, rapid and subtle responses appear to be well established by 7 years of age (e.g., Eisenberg et al., 1988; Scambler et al., 2007).

Experiment 2

In addition to examining the occurrence and mechanisms of RFRs in typically developing children, the existence, patterns, and mechanisms of RFRs in atypically developing children with social–emotional difficulties, such as those seen in ASD, also warrant investigation. Autism is a complex neurodevelopmental disorder encompassing significant heterogeneity in symptom severity. The term *autism spectrum disorder* is used to reflect the heterogeneity of impairments, which range from mild to severe. Experiment 2 explored RFRs in children with known deficits in social and communicative functioning who met criteria for any autism spectrum disorder (e.g., autistic disorder, Asperger syndrome, pervasive developmental disorder–not otherwise specified).

Characteristics of ASD include impaired social and emotional interactions, impaired communication abilities, and restrictive and repetitive behaviors or activities (American Psychiatric Association.,

2000). Deficits in matching reactions have been proposed as core problems in autism (Hepburn & Stone, 2006; Moody & McIntosh, 2006; Rogers, 1999, 2006; Rogers & Pennington, 1991). In addition, problems with emotional contagion have been found to be ASD specific in 2-year-olds relative to developmentally matched controls with and without disabilities (Scambler et al., 2007). At 2, 5, and 8 years of age, children with ASD are reported by their parents to be more likely than comparison children with and without other disabilities to demonstrate restricted affect and affect incongruous with environmental stimuli (Hepburn, Philofsky, Fidler, & Rogers, 2005). Moreover, the overt facial expressions of children with ASD have been reported to be flat or blended (Yirmiya, Kasari, Sigman, & Mundy, 1989). Given the importance of emotion matching to social functioning, it is likely that the disruption of matching behaviors may lead to an atypical social–emotional development such as is seen in children with ASD. Previous studies have examined matching behaviors through visual observation of facial expressions and behavior. By using facial EMG, we are able to assess facial muscle activation that occurs rapidly, measured in milliseconds, and we are able to record subtle movement that would go undetected by the eye.

Adults with ASD show atypical RFRs to emotional faces. High-functioning adults with ASD do not display the typical pattern of quick and spontaneous RFRs to happy and angry emotional expressions even though they can match expressions when asked (McIntosh et al., 2006). That adults with ASD have atypical RFRs is consistent with the idea that emotional mimicry is important to the development of typical social–emotional functioning. Studying children with ASD allows a developmental perspective of the characteristics and mechanisms of RFRs in atypical social–emotional development.

Experiment 2 builds on the findings from Experiment 1 by examining RFRs in a sample of children with ASD. Previous work leads us to expect that children with ASD will not show typical patterns of RFRs. RFRs may be absent or may reflect unusual combinations of muscular activation. This finding would be consistent with the idea that atypical RFRs are related to basic dysfunction in ASD; moreover, by evaluating the association between symptom severity and degree of matching, this study evaluates how strongly matching RFRs are related to ASD impairments.

Method

Participants

A total of 11 children (10 boys and 1 girl) with a current clinical diagnosis of ASD ($n = 6$), Asperger syndrome ($n = 3$), or pervasive developmental disorder–not otherwise specified ($n = 2$) participated in the study. Children ranged in age from 8 to 13 years with a mean age of approximately 10 years ($M = 10$ years 6 months, $SD = 1$ year 11 months, $Mdn = 10$ years 7 months, range = 8 years 0 months to 13 years 4 months). Specific diagnosis was evenly distributed over age. In addition, 1 participant was tested but not included in the final sample because he was unwilling to complete the session (7-year-old boy). The majority of the sample was Caucasian (72.7%), with 18.2% African American and 9.1% Hispanic. Mother's education was used as the index of socioeconomic status, with 18.3% being high school graduates, 9.1% completing some college, 18.2% graduating from college, and 54.5% completing college and pursuing advanced degrees. Compensation for participation was the same as in Experiment 1.

All participants were recruited from a longitudinal study of the developing phenotype of autism between 1996 and 2006 at the University of Colorado at Denver, School of Medicine. Inclusion criteria were as follows: confirmed diagnosis on the autism spectrum and a Full Scale IQ score above 70 (Full Scale IQ, $M = 104$, $SD = 19$, range = 81–139; Verbal IQ, $M = 100$, $SD = 26$, range = 53–144; and Perform IQ, $M = 107$, $SD = 16$, range = 88–133) (Psychological Corporation., 1999). None of the children had a significant medical condition (e.g., seizure disorder), a history of prematurity, or developmental regression. Adaptive functioning, measured by the Vineland Adaptive Interview Scales (VABS) (Sparrow, Balla, & Cicchetti, 2005) was reported by parents to be significantly impaired (i.e., $\geqslant 1.5$ standard deviations below the mean of 100) ($M = 69.36$, $SD = 7.46$, range = 58–82).

All children participated in a comprehensive evaluation for autism that included a parent interview of symptoms (the Autism Diagnostic Interview– Revised (ADI-R) (Lord & Rutter, 1994) and/or

the Social Communication Questionnaire (SCQ) (Berument, Rutter, Lord, Pickles, & Bailey, 1999) and direct observation of social and communicative behaviors via the Autism Diagnostic Observation Schedule (ADOS) (Lord et al., 2000). All children obtained scores within the autism range on one or both parent interviews as well as on the ADOS. In addition, all children participated in 10 or more hours of observation and interview through the study, providing rich information across a variety of functioning areas so that the lead clinician (S.L.H.) could determine a current clinical diagnosis. Reliability on diagnostic classifications was conducted by asking a second clinical psychologist to review the records on at least 50% of the sample ($n = 6$), and agreement on diagnosis was 100%. All 11 children, regardless of developmental history, presented as significantly impaired socially and exceeded the cutoffs for autism both on the direct measure of social functioning and by parent report.

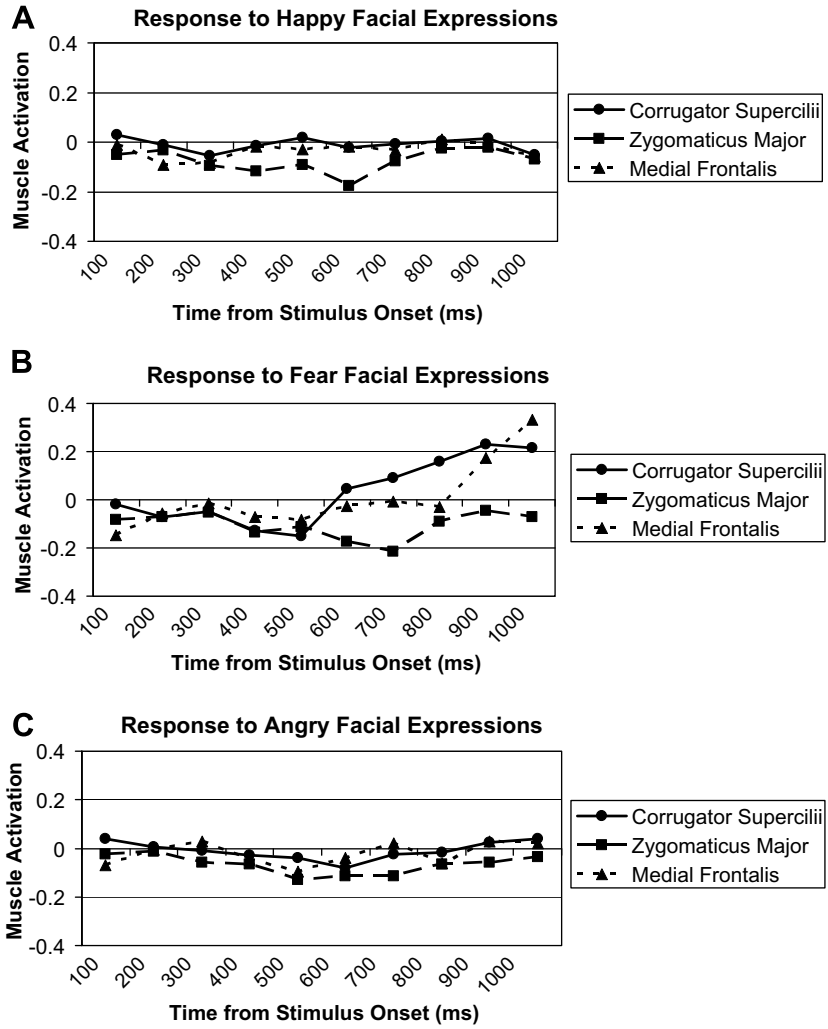

Fig. 2. EMG responses in Experiment 2 for children with ASD. These are averaged, baseline-corrected responses for each 100-ms window following onset of happy emotion faces (A), fear faces (B), and angry faces (C) for all three muscles. Muscle activation differs significantly over time for fear expressions.

Apparatus, stimuli, procedure, and measures

The apparatus, stimuli, procedure, and measures were identical to those in Experiment 1.

Results and discussion

As in Experiment 1, data were examined for movement artifacts, inattention to the stimulus, and participant interference with electrodes. Based on videotape analysis, participants generally oriented to the stimuli, and only seven trials were excluded from analyses. Furthermore, children tolerated the facial electrodes throughout the experiment and did not dislodge any of them. Finally, the muscle responses were sufficient to analyze the data using standard procedures.

We conducted three repeated measures ANOVAs—one for each emotion (happy, fear, or angry)—using averaged poststimulus muscle activity data: 3 (Muscle: corrugator supercilii, frontalis, or zygomaticus major) × 6 (Time: 500, 600, 700, 800, 900, or 1000 ms poststimulus onset). For responses to happy expressions, there was no significant main effect of muscle, $F(2, 20) < 1$, *ns,* partial $\eta^2 = .06$, or of time, $F(5, 50) = 1.30$, *ns,* partial $\eta^2 = .12$), and there was no Muscle × Time interaction, $F(10, 100) = < 1$, *ns,* partial $\eta^2 = .05$. Children with ASD did not appear to produce RFRs in response to happy faces (Fig. 2A). Thus, children with ASD demonstrated neither motor matching nor emotional RFRs in response to happy faces.

In contrast, the ANOVA for responses to fear faces indicated a significant main effect of time, $F(5, 50) = 2.51$, $p < .05$, partial $\eta^2 = .20$, and a significant Muscle × Time interaction, $F(10, 100) = 3.24$, $p < .01$, partial $\eta^2 = .25$), but no main effect of muscle, $F(2, 20) = 2.73$, *ns,* partial $\eta^2 = .21$. Children with ASD first showed enhanced activation of the corrugator muscles around 600 ms and subsequently showed a blended corrugator and medial frontalis response starting around 800 ms (Fig. 2B). This pattern of activation appears to be different from that of the typically developing children in Experiment 1, who showed no such activation. Moreover, although the adult pattern of facial activation to fear faces is not well established, what the children with ASD displayed here appears to differ from what is displayed by typically developing adults viewing fear expressions after a fear induction task (Moody et al., 2007). The combination of frontalis and corrugator activation seen in Experiment 2 is consistent with clinical observations of individuals with ASD who tend to show blended or mixed responses to emotional stimuli (Yirmiya et al., 1989).

For the ANOVA on responses to angry faces, there was no significant main effect of muscle, $F(2, 20) < 1$, *ns,* partial $\eta^2 = .09$, no main effect of time, $F(5, 50) = 2.11$, *ns,* partial $\eta^2 = .17$, and no Time × Muscle interaction, $F(10, 100) < 1$, *ns,* partial $\eta^2 = .06$. Children with ASD did not appear to produce RFRs in response to angry faces. Thus, children with ASD demonstrated neither motor matching nor emotional RFRs in response to angry faces (Fig. 2C).

As in Experiment 1, we conducted exploratory analyses to examine whether the degree to which children with ASD matched observed facial expressions is related to age. Furthermore, we examined whether matching RFRs were associated with severity of ASD (scores from the ADOS provided a measure of severity, with higher scores indicating greater severity) or Full Scale IQ. As in Experiment 1, for each expression (happy, angry, or fear), we assessed matching RFRs by computing a difference score indicating how congruent each child's facial response was to the expression she or he was viewing.

Table 1
Correlations between matching RFR difference scores and age, severity of autism and IQ for each facial expression in Experiment 2

Measure	Matching RFRs difference score: Facial expression congruence		
	Happy	Fear	Angry
Age	.82*	.11	.48
Severity of autism	−.01	−.22	−.01
Full Scale IQ	−.20	.12	−.21

Note. Matching RFR difference scores were calculated by subtracting incongruent muscle activation from congruent muscle activation. Larger positive different scores indicated greater matching RFRs. For all analyses, $df = 9$ except for severity of autism ($df = 8$).

* $p = .002$, which is less than the critical value of .008 (two-tailed).

Pearson correlation coefficients were calculated between degree of matching RFRs and age, severity, and IQ. Table 1 displays these correlations for each emotional face stimulus (happy, angry, or fear). There was a significant positive correlation between age and degree of matching of happy faces, $r(9) = .82$, $p = .002$ (two-tailed, critical value set at .008 to prevent inflation of family-wise alpha > .05). As displayed in Fig. 3, as age increased in children with ASD, the tendency to display a facial expression matching observed happy facial expressions increased. The next strongest effect was the correlation between age and matching of angry faces, although the correlation was nonsignificant, $r(9) = .48$, $p = .13$. There was no significant relation between severity of autism or Full Scale IQ scores and degree of matching RFRs for any of the three emotional faces.

In sum, the patterns of RFRs seen in children with ASD do not appear to be typical. There was little evidence of motor or emotion-based matching of angry or happy faces that is evident in typically developing children (in Experiment 1) and adults. As a group, the children with ASD did not display expressions that matched the faces they viewed. Thus, neither the motor matching nor emotional response mechanisms appeared to be consistently present among children with ASD. Moreover, children's responses to fear faces contrasted with the absence of RFRs found among the typically developing children in Experiment 1. The RFRs to fear faces also contrasted with enhanced frontalis activation often seen in typical adults; instead, a blended atypical pattern of RFRs to fear faces was observed. This blended atypical pattern is somewhat similar to that seen in adults with ASD who displayed high levels of activation in muscles not related to the faces viewed (McIntosh et al., 2006). These results suggest that RFRs to emotional facial expressions do not develop typically in children with ASD.

Although the exploratory correlational analyses between matching RFRs and severity of autism and Full Scale IQ were not significant, the high likelihood of a Type II error makes interpretive caution warranted. The statistical power for these correlations with the current sample ($N = 11$) was poor (power $\leqslant .10$). Thus, further research should be conducted with a larger sample size to assess these associations.

The association between age and congruency of rapid facial responses to happy faces suggests that matching RFRs to this emotion improve from 8 to 13 years of age in children with ASD. The degree of the association was large. Future research should examine RFRs in children with ASD in this critical

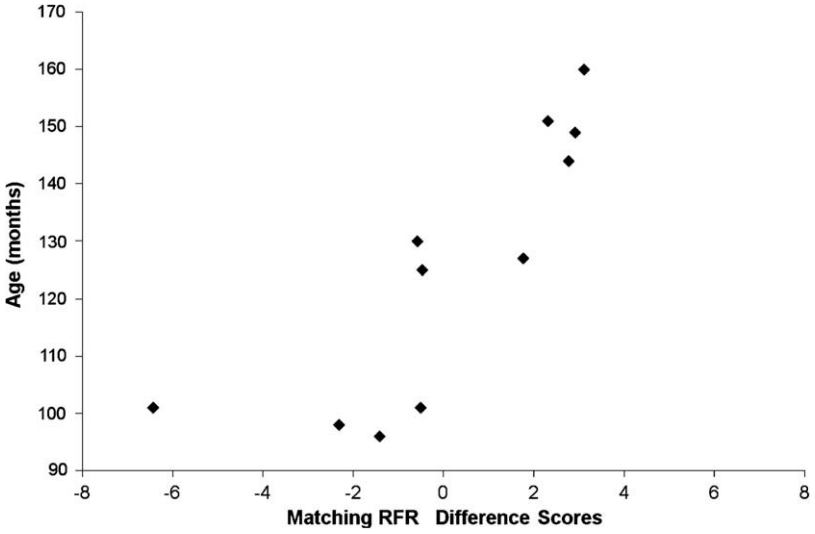

Fig. 3. Scatterplot of age and degree of matching happy facial expressions among children with ASD in Experiment 2, $r(9) = .82$, $p = .002$. Matching RFR difference scores were calculated by subtracting incongruent muscle activation from congruent muscle activation (500–1000 ms poststimulus). Larger positive difference scores indicated greater matching RFRs.

age group to further explore the nature and causes of this association. As discussed below, it raises interesting questions when considered in the context of Experiment 1 and other findings.

General discussion

This study confirmed that quick and subtle RFRs to emotional facial expressions can be assessed with EMG in typically developing children and children with ASD. It investigated two possible underlying mechanisms of RFRs, motor mimicry and emotional responses, and confirmed the existence of an emotional mechanism in typically developing children from 7 to 12 years of age. Experiment 1 found RFRs to happy and angry expressions in typically developing children, consistent with those found in adults. Our findings suggest a robust and automatic effect that occurs to still two-dimensional photographs (even black and white photographs) on a screen. Given the specific patterns of muscle activation observed, RFRs appear to include emotional responses and, thus, are not purely the result of motor matching. Experiment 2 found that the group of children with ASD did not produce consistent RFRs to happy or angry faces and that their facial responses to fear expressions were undifferentiated. Children with ASD exhibited an improvement in matching RFRs to happy faces between 8 and 13 years of age.

These findings have many implications given that RFRs may contribute to the development of various imitative, social, and emotional processes observed in developing children. For example, it is noteworthy that the findings for typically developing children are roughly commensurate with findings for adults. This suggests that these rapid subtle responses are well established by this age period and appear to be influenced by rapid affective processes, just as they appear to be in adults (Moody et al., 2007). This implies some developmental consistency in this mechanism of RFRs from middle childhood through adulthood. Sharing affect with a social partner is important for social reciprocity during childhood, adolescence, and adulthood (Keltner & Kring, 1998). Also, sharing another's emotional state is a cornerstone of the development of empathy and higher level social–emotional understanding (for a review, see Hatfield et al., 1994). Importantly, our findings suggest that even the most rapid responses to emotional facial expressions are influenced by emotions in this age group. Quick affective reactions to others' emotions are foundational to important emotional developmental tasks in this age group such as perspective taking, empathy, and peer interactions (Higgins & Parsons, 1983; Hoffman, 2000; Selman & Byrne, 1974). Further research should look at younger ages to examine what mechanisms operate earlier in development.

Understanding RFRs also has implications for identifying the connection between mimicry and complex imitation. Such imitation behaviors may build on components of the most simple behaviors such as automatic matching of emotional facial expressions (Moody & McIntosh, 2006; Rogers, 1999). However, determining the connections among basic matching, automatic mimicry, and complex imitation will require systematic consideration of the mechanisms involved. For example, in infants, early and later matching may be produced by different mechanisms and abilities (Jones, 2007). Therefore, continued identification of the mechanisms of RFRs across development is needed to discern the extent to which imitation builds on the differing processes leading to observed matching.

RFRs in children with ASD did not follow typical patterns. At the group level, RFRs to both happy and angry expressions were not discernable. Although this null effect should be interpreted with caution, the lack of RFRs to these expressions is consistent with reports of generalized flattened affect (Yirmiya et al., 1989). RFRs did occur in children with ASD in response to fear expressions; however, the RFRs were undifferentiated responses (delayed activation of both corrugator and frontalis muscles). There was no activation of the zygomatic muscles, which would have raised the cheeks and resembled a smile. Thus, children with ASD produced a blended expression of an angry scowl (corrugator muscles) with raised eyebrows (frontalis muscles). Atypically mixed muscle activation may contribute to blended expressions seen with standard observations in children with ASD (Yirmiya et al., 1989). In general, the absence of discernable and congruent responses among children with ASD suggests that they might not be sharing the emotion or responding typically to the emotion of the person being observed or that they might be confused about the nature of the emotion being displayed. These findings point to the need for future work to explore both the development of mechanisms of RFRs and other specific processes that cause or influence RFRs (e.g., attention to faces).

Exploratory analyses in Experiment 2 suggest some possibilities for such future work. A more nuanced analysis of the ASD group's responses showed that age was strongly and significantly related to the tendency to match happy faces and was moderately (but not significantly) related to the tendency to match anger expressions. Combined with other findings, this pattern raises important questions. Most clearly, the association of matching RFRs with age suggests that between 8 and 13 years of age, children with ASD may be developing mechanisms that facilitate matching of others' expressions. Furthermore, one interpretation of the undifferentiated responses to fear is that matching responses are developing but not yet fully established. The emergence during this age period may simply reflect a delay of mechanisms that typically developing individuals have developed earlier; this is consistent with the absence of an age effect in the typical children examined in Experiment 1. However, because adults with ASD do not show typical mimicry to facial expressions in a similar facial EMG paradigm (McIntosh et al., 2006), it seems unlikely that the pattern reflects simple delayed development. It may be that atypical strategies are being developed in compensation for the absence of the mechanisms present in typically developing individuals. Indeed, adolescents (15–18 years of age) and adults with ASD use a more piecemeal, rule-based strategy in emotion perception in comparison with the more template-based approach used by typically developing adults (Rutherford & McIntosh, 2007). The facial response observed in Experiment 2 may be evidence that such strategies are emerging during this age period.

One possible difference between typically developing children and those with ASD may be whether RFRs reflect emotional or motor responses. In Experiment 1, typically developing children appeared to respond emotionally to the angry face, expressing relatively more fear. However, the moderate (but not significant) correlation between age and anger expression in Experiment 2 suggests that children with ASD may begin to be matching anger expressions rather than showing the complementary emotional responses seen in typically developing children. The absence of an overall effect, however, indicates that further work examining RFRs to emotional faces will be critical to determining what is happening during this period. Testing this association with a larger sample would be particularly interesting and may provide further evidence for differences in processing of social–emotional information between children with ASD and typically developing children.

Identifying differential performance across tasks is important in understanding the nature of deficits in ASD. For example, one review reported that imitation skills improve with age, particularly for meaningful actions such as waving goodbye (Williams et al., 2004); in contrast, facial mimicry of emotions remains impaired (McIntosh et al., 2006). This impairment in mimicry, but not more goal-oriented imitation, suggests that a parietal route in the mirror neuron system for goal emulation may be relatively intact but that an occipital–frontal route for mimicry may be dysfunctional (Hamilton, 2008). The current findings are consistent with this view in that they indicate that mimicry is impaired in children with ASD. Continued examination of basic mechanisms of matching behaviors may indicate which processes are impaired and which ones are intact. This information may provide ideas for more focused treatments and indicate how these two routes interact in typical development.

Beyond the issue of underlying mechanisms, these findings suggest other possible sources of difficulties for children with ASD. For example, if the children with ASD do not respond as typically developing children do, then their interaction partners might not respond predictably to their expressions. It has been reported that mothers of children with ASD smile less often at their children with ASD (Dawson, Spencer, Galport, & Watson, 1990). Experiencing multiple atypical social interactions may itself influence the social development of individuals with ASD. In addition, atypical responses to others' emotional expressions could be associated with common deficits reported in ASD such as impoverished emotional recognition, limited range of affect, lack of spontaneous reciprocity, diminished empathy, and poor social–emotional understanding (Seltzer et al., 2003). If a child lacks experience in affective matching, she or he may miss many critical learning opportunities for identifying emotions in context and linking those emotional cues to behavioral responses. The result could be dysregulated emotional displays that may seem out of context, inappropriate, or extreme in intensity—all descriptions of affect that are consistent with persons with ASD across the life span (Seltzer et al., 2003).

In addition to the substantive issues addressed by the current study, this work provides methodological information useful for addressing the questions raised. To our knowledge, the current study

is the first to record RFRs in children using EMG. This study demonstrated that children (both typically developing children and children with ASD) from 7 to 13 years of age were able to tolerate the facial preparation necessary to place facial surface electrodes, tolerate the attachment of the surface electrodes, produce minimal movement artifacts (e.g., touching their faces, wiggling), and attend to the stimuli appropriately. All of these criteria are necessary to record reliable EMG data. Demonstrating reliable EMG data in children as they observe facial expressions advances the utility of this method in examining the developmental course and understanding of rapid responses. Moreover, it is particularly significant that this method was successful with an atypical developmental sample such as children with ASD, wherein sensory defensiveness is often described (Rogers, Hepburn, & Wehner, 2003).

Limitations and future studies

Despite the contributions of this study, several limitations and findings suggest the benefit of additional work. Future work should more thoroughly examine RFRs in children with ASD by using larger samples and matched comparison samples of children with other developmental delays. Increasing sample size would provide a more statistically powerful test of whether severity of ASD and IQ are related to RFRs and of whether RFRs are absent, diminished, or undifferentiated in children with ASD compared with typically developing children.

Finding RFRs in this age group should encourage work exploring the presence and nature of RFRs in younger samples. Work across age groups will allow a better understanding of the development of RFRs and whether responses earlier in development are more motor mimicry or emotional in character or whether they tend to develop together. In addition, the successful use of an individual index of matching expressions (i.e., matching RFR difference scores) and its association with age opens the door to further examination of individual differences in matching ability in typically developing children and those with ASD. Finally, although work in adults has tied RFRs to social and emotional processes, only by examining RFRs from a developmental standpoint can we discern the nature of their relation to processes such as imitation, emotional contagion, emotional regulation, and range and spontaneity of affective displays.

Additional work is needed to continue to disentangle the mechanisms underlying RFRs. Although the display of fear to an angry face in Experiment 1 indicates an emotional influence, our data cannot distinguish between motor matching and emotional responses to happy faces. Expressions that match those observed may be related to motor matching, emotional responses, or both. One goal for future work is to examine the developmental paths of both mechanisms and to untangle their relative influences in specific circumstances.

Summary

By examining a very rapid matching behavior in typically developing children and children with ASD, the current study not only demonstrated that such responses occur during childhood and suggested that they may be important in typical social–emotional development but also provided evidence that emotional response is an underlying mechanism of at least some of these rapid responses. In addition, the finding that RFRs appear to be undergoing a developmental change in children with ASD during middle childhood emphasizes the necessity for future exploration. Exploring mechanisms of social and emotional responses in this age group appears to be critical to understanding the processes involved in social functioning in people with ASD. Future exploration is necessary so that we may continue to gain insight into the nature, causes, and consequences of this basic interpersonal response that may help us to socially and emotionally relate one to another.

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