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PAPER

Undifferentiated facial electromyography responses to dynamic, audio-visual emotion displays in individuals with autism spectrum disorders

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Abstract

We examined facial electromyography (fEMG) activity to dynamic, audio-visual emotional displays in individuals with autism spectrum disorders (ASD) and typically developing (TD) individuals. Participants viewed clips of happy, angry, and fearful displays that contained both facial expression and affective prosody while surface electrodes measured corrugator supercilli *and* zygomaticus major *facial muscle activity. Across measures of average and peak activity, the TD group demonstrated emotion-selective fEMG responding, with greater relative activation of the zygomatic to happy stimuli and greater relative activation of the corrugator to fearful stimuli. In contrast, the ASD group largely showed no significant differences between zygomatic and corrugator activity across these emotions. There were no group differences in the magnitude and timing of fEMG response in the muscle congruent to the stimuli. This evidence that fEMG responses in ASD are undifferentiated with respect to the valence of the stimulus is discussed in light of potential underlying neurobiological mechanisms.*

Introduction

Social interaction depends on the ability to perceive and interpret emotional cues (e.g. facial expression, tone of voice, body posture) presented by interactive partners, to adapt one's behavior based on these cues, and in turn, to use them to regulate the interaction. Since Kanner's (1943) classic description of autism first emphasized a disturbance in the ability to form affective contact with others as a key feature, a large body of research has identified difficulties in perceiving, expressing and responding to emotional cues in individuals with autism (Hobson, 2005). Along with behavioral evidence, measures of physiological reactivity have increasingly been employed to gauge components of the emotion processing and response system in autism. Physiological measures lend insight into experiential, automatic processes involved in affect processing that are not under intentional control, and are well suited to exploring potential mechanisms underlying emotion perception difficulties among individuals with autism spectrum disorders (ASDs). In the present study, we utilized facial electromyography (fEMG) to examine the psychophysiological underpinnings of dynamic emotion perception in ASD.

It has long been noted that observing another person's expression of emotion elicits distinct patterns of facial muscle activity in the observer that reflect a matching response. These patterns are typically too small and fleeting to be perceived visually but can be reliably detected by surface electrodes placed over facial muscle regions using facial electromyography (fEMG). They include covert increases in activity of the corrugator supercilli (which typically knits the brows into a frown) in response to negative emotions and increases in the zygomaticus major (which pulls the cheeks and lips into a smile) in response to positive emotions (Dimberg, 1982, 1988). Evidence that activity in these muscle regions differentially represents the valence of the perceived stimulus has been demonstrated for static and dynamic facial emotional displays (Achaibou, Pourtois, Schwartz & Vuilleumier, 2008; Dimberg, 1982; Hess & Blairy, 2001; Sato & Yoshikawa, 2007) and emotion cues that do not involve faces, such as voices or body postures (Bradley & Lang, 2000;

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Hietanen, Surakka & Linnankoski, 1998; Magneé, Stekelenburg, Kemner & de Gelder, 2007b).

These 'facial mimicry' reactions fall along a continuum of interpersonal processes that involve matching others' expressions and movements (Moody & McIntosh, 2006) and are critical to socio-emotional functioning (de Wied, van Boxtel, Zaalberg, Goudena & Matthys, 2006; Sonnby-Borgstrom, Jonsson & Svensson, 2003). However, unlike imitation or other forms of intentional, goal-directed movements, fEMG reactions are rapid, occurring as early as 300 ms within stimulus onset, and automatic; they are observed when the visual stimulus is presented outside of the observer's conscious awareness (Dimberg, Thunberg & Elmehed, 2000) and are difficult to voluntarily interrupt and restrain (Dimberg, Thunberg & Grunedal, 2002). These characteristics make facial mimicry particularly well suited to studying the mechanisms that underlie observed difficulties in emotion processing in autism. For example, individuals with ASD may rely on more effortful cognitive compensatory strategies such as verbal mediation, learned associations and prototypical references to reason about emotions (Capps, Yirmiya & Sigman, 1992; Grossman, Klin, Carter & Volkmar, 2000; Lindner & Rosen, 2006). Because fEMG reactions are rapid and automatic, they may be less influenced by factors such as motivation and learning, and less obscured by compensatory strategies (Moody & McIntosh, 2006). Research that examines fEMG to emotional content has the potential to illuminate fundamental neurobiological processes underlying difficulties in emotion recognition and processing in ASD.

Current proposals regarding mechanisms of mimicry and its role in emotion processing similarly have implications for autism. Some researchers propose that mimicry is strictly a non-affective motor response. The observed matching reaction is a motor action generated in response to perceiving a facial expression (Chartrand & Bargh, 1999; Hatfield, Cacioppo & Rapson, 1993; Hoffmann, 1984), which only subsequently engenders an emotional response in the observer through facial feedback processes (Hatfield, Cacioppo & Rapson, 1994; McIntosh, Druckman & Zajonc, 1994). Within this view, mimicry deficits in autism are related to other behavior matching disruptions commonly observed in this group, such as those involving imitation and echolalia (Moody & McIntosh, 2006). Others argue that facial mimicry is itself an affective reaction to the perceived emotional stimulus (Cacioppo, Martzke, Petty & Tassinary, 1988; Dimberg, 1997; Winkielman & Cacioppo, 2001). Hence, the observed facial reaction reflects a matching emotional response in the observer, mediated by the brain's emotional systems. In support of this view, research indicates that fEMG activity differentiates the valence and intensity of participants' affective reactions to stimuli (Cacioppo, Petty, Losch & Kim, 1986), is accompanied by corresponding changes in perceived emotion (Dimberg, 1988), can be modulated by the induction of particular emotions in the observer (Moody, McIntosh, Mann & Weisser, 2007), and that blocking facial muscle responses interferes with recognition of specific emotional expressions (Oberman, Winkielman & Ramachandran, 2007). Under this proposal, any observed disruptions in facial mimicry in autism point to disruptions in brain systems involved in affective processing (Moody & McIntosh, 2006).

Ultimately, both motor and affective processes are likely involved in facial mimicry responses, as recently demonstrated in a compelling study (Moody & McIntosh, 2011) that compared facial mimicry to stimuli containing emotional movement (happy and angry facial expressions) to those containing non-emotional movement (stuttering, arm wrestling). Facial mimicry was observed in response to facial displays of emotion and to non-emotional facial displays (stuttering), indicating that mimicry is at least partially driven by motor-mimetic processes. However, the magnitude of mimicry was greater in response to emotional facial expressions than non-emotional motor movements, suggesting separable motor and affective processes in mimicry that may operate on their own or in conjunction (Moody & McIntosh, 2011). In light of these findings, observed patterns of mimicry in ASD may suggest underlying disruptions in motor (perception-action) processes, affective processes, or perhaps both.

To date, four studies have utilized fEMG in individuals with ASD and age and IQ-matched typically developing controls. The first reported a nonspecific pattern of activity in a sample of adults, with comparable levels of corrugator and zygomatic activity in response to static facial expressions of happiness and anger (McIntosh, Reichmann-Decker, Winkielman &Wilbarger, 2006). Undifferentiated fEMG activity was subsequently observed in a sample of children, though only for fearful expressions; no discernable fEMG responses were detected in response to happy or angry faces (Beall, Moody, McIntosh, Hepburn & Reed, 2008). In contrast to these two studies, which presented stimuli using a passive viewing format, normative patterns of fEMG responses were reported for children with ASD when the experimental conditions explicitly called for emotion recognition (Oberman, Winkielman & Ramachandran, 2009). The ASD group showed comparable levels and selectivity of emotion-relevant fEMG response to typically developing controls when asked to label the emotion in each picture, though their responses were

delayed across the range of emotional expressions presented. Finally, when presented with a task in which static faces were paired with simultaneously presented voices that either matched or did not match the facial expression, adults with ASD demonstrated normal integration of audio-visual emotional stimuli, as evidenced by increased activity in the relevant muscle for emotionally congruent compared to incongruent face-voice pairs (Magneé, de Gelder, van Engeland & Kemner, 2007a).

Several questions regarding mimicry to facial expressions of emotion in individuals with ASD emerge from previous work. The first concerns the use of static versus dynamic content. The static stimuli in previous research include intense and prototypical expressions that arguably may elicit a reflex-like fEMG response due to their extremity (Hess & Blairy, 2001). In contrast, naturalistic, low-intensity dynamic stimuli typically modulate the degree of mimicry observed (Hess & Blairy, 2001; McIntosh, 2006), and recruit more extensive neurological systems and elicit greater activation in emotion-related brain regions than static presentations (Sato, Kochiyama, Yoshikawa, Naito & Matsumura, 2004). Previous studies did not evaluate facial mimicry to dynamic emotional displays in ASD, despite the fact that stimuli that require more rapid and complex information processing may be needed to uncover more subtle deficits in processing of basic emotions (e.g. happiness, anger, fear) in autism (Humphreys, Minshew, Leonard & Behrmann, 2007). In light of empirical evidence that mimicry to facial displays of emotion may be the result of both motor and affective processes (Moody & McIntosh, 2011), the use of dynamic stimuli can shed light on potential mechanisms underlying disrupted facial mimicry to emotion in ASD.

The second issue concerns the modality through which the emotional information is conveyed. All but one of the previous studies of fEMG in ASD utilized stimuli consisting solely of emotionally expressive faces. Even in the Magneé *et al*. (2007a) study, the vocal information consisted of an audio track played simultaneously with presentation of a static face. Facial mimicry to such stimuli may not mirror emotion processing as it occurs in the course of everyday interactions, where emotions are perceived in a multisensory context that includes dynamic facial expression and affective prosody. The perception of emotion in the face is influenced by the emotion conveyed by the tone of voice (de Gelder & Bertelson, 2003; Massaro & Egan, 1996) and audio-visual emotion integration is subserved by unique patterns of brain activation (Robins, Hunyadi & Schultz, 2009). Previous behavioral research suggests that individuals with ASD have particular difficulty recognizing the correspondence between emotionally expressive faces, gestures, and vocalizations (e.g. Hobson, Ouston & Lee, 1988; Loveland, Steinberg, Pearson, Mansour & Reddoch, 2008; Macdonald, Rutter, Howlin, Rios, Le Conteur, Evered & Folstein, 1989), and the disruption in the ability to integrate emotional information across auditory and visual modalities can be observed at the neural level (e.g. Hall, Szechtman & Nahmias, 2003; Magneé, de Gelder, van Engeland & Kemner, 2008). The use of audio-visual stimuli may lend insight into psychophysiological mechanisms underlying the difficulties in real-world emotion perception in ASD and shed light on unique patterns of facial mimicry responses when the task calls for multimodal emotion perception.

The final issue pertains to attention. More normative patterns of fEMG activity have been observed in ASD when the experimental conditions ensured that participants paid attention to the emotional dimension of the stimuli, whether by explicitly asking them to identify the emotion or implicitly by pairing voices with facial expressions. However, studies with neurotypical individuals indicate that neural processing of emotional faces requires attention (Pessoa, McKenna, Gutierrez & Ungerleider, 2002), and there is evidence that attention to the eyes modulates brain activity to face stimuli in ASD (Dalton, Nacewicz, Johnstone, Schaefer, Gernsbacher, Goldsmith, Alexander & Davidson, 2005). Thus, experimental cues to ensure that participants pay attention to the emotional aspect of the stimuli may remove a potential attentional confound on observed fEMG responses in ASD.

The aim of the current study is to begin to explore the questions raised by previous studies by examining fEMG to dynamic audio-visual emotion displays among children and adolescents with ASD. The focus on realistic, dynamic emotional stimuli allows us to take a step toward exploring underlying mechanisms behind facial mimicry in individuals with ASD, whereas the inclusion of auditory information allows us to examine how mimicry is affected when the task involves multimodal emotion perception. We further embedded a forced-choice emotion identification task within our fEMG experimental paradigm in order to minimize the chances that any atypical patterns of facial mimicry observed in the ASD group are due to a failure to pay attention to the emotional dimension of stimuli. Based on previous behavioral work on emotional expressiveness in ASD (Yirmiya, Kasari, Sigman & Mundy, 1989) and previous fEMG studies with static faces (Beall *et al*., 2008; McIntosh *et al*., 2006), we hypothesize that individuals with ASD will demonstrate atypical fEMG responses to dynamic, audio-visual displays of positive (happy) and negative (angry, fearful) emotions that will be

characterized by muscle activity undifferentiated with respect to the valence of the emotion. Given inconclusive prior findings and the diverse statistical approaches presented in prior studies, we examine the current hypothesis using fEMG mean activity, peak magnitude, as well as time course analyses.

Methods

Participants

Seventeen individuals with a clinical diagnosis on the autism spectrum (ASD; Autistic Disorder, Asperger's, PDD-NOS) and 17 typically developing (TD) controls participated in an fEMG session as part of a larger study. Participants were recruited through advertising in publications and on websites frequented by families of individuals with ASD, direct recruitment at events attended by these families, referrals from professionals in the local community, and by word of mouth. TD participants were recruited from local schools, churches, and other community organizations and word of mouth. Diagnoses were confirmed via the Autism Diagnostic Interview-Revised (Lord, Rutter & LeCouteur, 1994) and the Autism Diagnostic Observation Schedule (Lord, Risi, Lambrecht, Cook, Leventhal, DiLavore, Pickles & Rutter, 2000). Participants in the TD group were screened for the presence of ASD symptoms with the Social Communication Questionnaire (Rutter, Bailey & Lord, 2003). Descriptive information about the sample can be found in Table 1. There were no group differences in age, IQ, WASI subtest age equivalents, and facial recognition as measured using the Benton Face Recognition Test (Benton, 1994).

Despite the presence of a handful of adults in both groups, preliminary analyses indicated that the pattern of results reported below did not appreciably change by restricting the sample to those younger than 18, nor those younger than 13 years of age. To increase power, analyses include data from all available participants.

An additional 21 participants were enrolled but not included in the analyses because they failed to meet diagnostic criteria ($n_{ASD} = 5$, $n_{TD} = 1$) or because data cleaning procedures revealed a large number of dropped trials due to excessive movement artifacts ($n_{ASD} = 5$, $n_{TD} = 10$; see fEMG Data Reduction and Analysis section below for details). Individuals whose data were dropped did not differ from those whose data were retained in the analyses on age, IQ as measured using the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999), and group membership (all *p*s > .3).

Table 1 *Sample characteristics*

	ASD group $n = 17$	TD group $n = 17$	Group comparison
Age			
Mean (*SD*)	16.6 (9.2)	15.2 (5.4)	$t(32) = -0.57$, $p = .6$
Range	9–31	7–44	
% Below 18	71%	71%	
Sex (% male)	71%	76%	
Ethnicity (% White)	82%	65%	
WASI			
Verbal IQ	103.1 (15.5)	107.6 (10.1)	$t(32) = 0.98$, $p = .3$
Vocabulary AE[a]	16.0 (7.7)	18.3 (7.6)	$t(32) = -0.87$, $p = .4$
Similarities AE	19.0 (9.3)	17.7 (7.5)	$t(32) = 43$, $p = .7$
Performance IQ	101.8 (22.0)	110.4 (10.8)	$t(23.6) = 1.43$, $p = .2$
Block design AE	16.3 (9.0)	20.0 (8.7)	$t(32) = -1.19$, $p = .2$
Matrix reasoning AE	18.8 (9.7)	22.2 (8.0)	$t(30.9) = -1.1$, $p = .3$
Benton Face Recognition Test	39.7 (3.7)	42.1 (5.3)	$t(32) = 1.29$, p = .2
EMG forced-choice task			
% Correct	70.9 (10.0)	69.4 (6.1)	$t(24.6) = -0.5$, p = .6
Response time (ms)	1169.9 (465.6)	1025.9 (427.0)	$t(32) = -0.93$, p = .4

Degrees of freedom adjusted based on significant Levene's test for equality of variances. [a]AE = age equivalent.

Stimulus materials

Stimuli consisted of dynamic, audio-visual emotional displays (DAVE stimuli; Robins *et al.*, 2009),[1] which include an actor (one male, one female) delivering one of 10 sentences in one of four emotions (angry, fearful, happy, and neutral). Each emotion is consistent with the semantic content of every sentence. For example, 'It's across the street' can be expressed as angry if the speaker is frustrated that a taxi pulled up to the wrong house, fearful if the speaker is scared of an approaching dog, happy if the speaker has spotted a ball that rolled away, and neutral as a statement of fact. Stimuli contain affect conveyed through both facial expression and tone of voice. The emotion is present in the face from the first frame (30 ms) of each stimulus, and the audio onset occurs within 100 ms of the onset of the stimulus.[2]

In the current study, participants viewed 36 DAVE stimuli, including eight each of congruent happy, angry,

[1] Those interested in using the DAVE stimuli in their research should contact Diana Robins at drobins@gsu.edu.

[2] DAVE stimuli were previously validated via two behavioral pilot studies. Initially, we ascertained that each unimodal presentation (face alone and voice alone, 80 stimuli each) was accurately perceived by at least 85% of a college student sample ($n = 16$) using a forced-choice format. Next, 80 audio-visual stimuli were presented to a new sample of students ($n = 37$), who selected from 15 possible labels to describe each emotion. Matching movies were correctly labeled 88% of the time (82% for neutral, 83% for angry, 91% for fearful, and 95% for happy).

and fearful displays, and 12 congruent neutral displays, interspersed among 36 incongruent stimuli in which the emotion conveyed by facial expression and tone of voice did not match. As the current study is the first to examine fEMG activity to dynamic audio-visual emotional stimuli in autism, the analyses reported herein focus on congruent happy, angry and fearful stimuli only. Of these 24 congruent stimuli, 20 ranged from 1.3 to 2 seconds in duration, and the remaining four ranged from 0.9 to 1.1 seconds.[3]

Procedures

The GSU Institutional Review Board approved all aspects of the study. Participants and legal guardians provided informed consent. Participants first washed their face using a mild cleansing soap, and were then seated comfortably while two examiners prepared their skin for application of surface electrodes using alcohol swabs and mild abrading pads. Two pairs of Ag/AgCl electrodes were placed bilaterally over the zygomaticus major (cheek) and corrugator supercilli (brow) muscle regions following standard guidelines (Fridlund & Cacioppo, 1986). Inter-electrode impedances were maintained at 10 KOhms or less, though in a few instances impedances of up to 25 KOhms were accepted when the target level could not be reached despite repeated attempts at site preparation and sensor placement. Participants were instructed not to touch their face and to minimize movement during the experiment. They were initially told that the electrodes measured sweating. Such deception is standard as it ensures that any facial muscle movements are not voluntary in response to participants' knowledge about the task. The true nature of the recordings was revealed during a post-experiment debriefing.

After electrode placement, we verified that participants were able to voluntarily make happy and angry facial expressions that resulted in observable changes in zygomatic and corrugator muscle activity. The examiner instructed the participant to make a happy face while demonstrating the expression. Once the participant imitated the expression, the examiner monitoring data collection from an adjacent room verified that the relevant muscle activation was observed. The procedure was repeated for the angry face. Participants then began the experimental task, starting with practice trials. The stimuli were presented on a 15-inch laptop computer placed about 56 cm from the participant (visual angle of approximately 5° horizontal × 4° vertical). One examiner remained in the room to monitor the participant–electrode/task interface, while the other monitored data acquisition from an adjacent room. fEMG signals were acquired at a sampling rate of 2500 samples per second utilizing BIOPAC (Santa Barbara, CA) hardware (EMG100c amplifier) and software (Acq*Knowledge* 3.7.3), synchronized with DirectRT software (Jarvis, 2006) used to present the stimuli.

The DAVE stimuli were presented in a forced-choice task. Participants wore headphones to ensure that they clearly heard the affective prosody in each stimulus and used a computer mouse to provide their responses. Participants completed several practice runs to ensure that they understood the task before proceeding with data collection. Each trial began with a screen that contained a prompt to judge whether a specific emotion was portrayed (e.g. 'Angry: Yes or No?'). After 2 seconds, one of the DAVE stimuli was presented, followed by a blank white screen with a question mark in the middle which served as a prompt for the participant to use the mouse to indicate *Yes* (left click) or *No* (right click) with his or her dominant hand in response to the question. During the practice runs, participants were instructed to 'Pay attention to the person's face and voice', decide whether the emotion cue presented before the movie correctly described 'how the person [was] feeling', and then to click *yes* or *no* to indicate their response. They were instructed to provide their answers as quickly as possible, although the screen remained blank for a random inter-trial interval of 10 to 15 seconds before the next question appeared on the screen. Each participant viewed four runs consisting of 18 trials each (approximately 8 minutes of run time each), with a brief break in between each run as the examiner switched to the next run. Run order was counterbalanced across participants.

fEMG data cleaning, reduction and analysis

Raw signals were filtered offline (low-pass filter of 500 Hz, high-pass filter of 20 Hz), integrated, and rectified. The signals were then screened for movement artifacts in the following manner. During data acquisition, a research assistant monitored overt facial movements by watching a live video feed from a camera zoomed in on the participant's face. He/she took detailed time-stamped notes regarding any movements (touching the face, making faces/smiling, talking, furrowing brows, facial twitches, sneezes/coughs) that occurred during stimulus presentation or the inter-trial period. The

[3] We independently verified that the emotion presented in the face for the 24 DAVE stimuli used in the current analysis could be correctly identified by 200 ms post-stimulus presentation by four individuals.

research assistant who remained in the room with the participant also took notes on trials during which the participant was not paying attention to the stimulus. Based on these two sets of notes and on visual inspection of the raw fEMG signals, a coder blind to the participants' group membership flagged all trials during which the participant did not pay attention to the stimulus or during which movement artifacts were observed during the baseline period or post-stimulus onset.[4] A second coder analyzed data from eight of the participants (16%) and attained 86% agreement on flagging individual trials. The number of dropped trials varied across participants. For the analyses, we retained data from 34 participants who had at least three valid trials for *each* emotion/muscle combination, though the majority of participants (n = 20) had at least five valid trials for each emotion type.[5] There were no group differences in the number of dropped trials.

For the purpose of analysis, each trial consisted of a pre-stimulus baseline (the 1000 ms period starting 2 seconds prior to the onset of the video, when the participant was looking at a blank screen) and a 1300 ms post-stimulus onset condition. All but four of the DAVE stimuli ranged in duration from 1300 to 2000 ms; hence, we analyzed activity within 1300 ms of stimulus presentation to equalize exposure to visual and auditory cues across the stimuli. However, we verified that the general pattern of results reported below was also observed when the analysis included the full 2000 ms post-stimulus onset. Analyses included data collected from the left side of the face, following research suggesting greater fEMG response on this side (Zhou & Hu, 2004). Baseline values for each trial were calculated by averaging activity over the entire 1000 ms baseline condition. fEMG activity post-stimulus onset was averaged in 100 ms intervals beginning with the stimulus onset and ending 1300 ms post-stimulus onset. The integral under the curve for each time window was calculated using software developed by the third author.[6]

Following McIntosh, Beall, Oberman, and colleagues, the integral values were used to calculate log-transformed standardized (z) scores. Integral values were $\log_{10}$ transformed to reduce the impact of extreme values, and standardized within participant and muscle. Change scores were calculated by subtracting the baseline activity from post-stimulus onset activity. Positive standard scores reflect increases in muscle activity relative to baseline, and negative standard scores indicate decreases in activity over baseline. Each participant's change scores were averaged separately for each emotion (happy, angry, fearful) and each muscle group (corrugator and zygomatic).

For response level, we first calculated the average amount of activity in the window of 500 to 1000 ms post-stimulus onset. This window was selected based on previous research suggesting that fEMG responses emerge and peak between 500 and 1000 ms after presentation of emotional stimuli (e.g. Dimberg, 1997). We also determined the value of the *peak magnitude* of fEMG activity, defined as the peak value through 1300 ms post-stimulus onset. The timing measure included the *latency to peak* response, the 100 ms bin post-stimulus onset during which the peak magnitude occurred. The peak magnitude and latency to peak measures were included to facilitate comparison of our results with previous studies of fEMG in autism. Finally, we analyzed the time course of responses across the entire period from stimulus onset to 1300 ms post-stimulus onset.

Results

The main goal of our analysis was to determine the extent to which fEMG activity in each group could be characterized by emotion-selective responding. Thus, for each emotion, we compared the activation in the emotion-congruent muscle (i.e. zygomatic to happy stimuli, corrugator to angry and fearful stimuli) to activation of the emotion-incongruent muscle (i.e. corrugator to happy stimuli, zygomatic to angry and fearful stimuli).

Analysis of behavioral responses to the forced-choice task indicated no group differences in accuracy or response time (see Table 1). A group by emotion ANOVA revealed no group differences in emotion recognition accuracy for happy, angry, or fearful stimuli, $F(2, 64) = 0.6$, $p = .6$. There was a main effect of emotion $F(1.5, 46.7)$[7] $= 29.1$, $p < .001$, as participants were less accurate in identifying fear (mean ASD = 54%; mean TD = 49%) than happiness (mean ASD = 72%; mean TD = 76%) and anger (mean ASD = 83%; mean

[4] A data-cleaning manual is available by contacting the corresponding author.

[5] Twenty participants had at least five valid trials of each emotion type (n_{ASD} = 10, n_{NT} = 10), 12 had at least four valid trials of each emotion type (n_{ASD} = 5, n_{NT} = 7), and only two had at least three valid trials of each emotion type (n_{ASD} = 2).

[6] Data reduction and all analyses were conducted using software developed by the third author. Details of the software are available upon request (richie@cc.gatech.edu).

[7] Because results of Mauchly's test indicated that the assumption of sphericity was violated, degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity.

TD = 82%). As an additional check, we examined the responses of a subset of participants to a separate, open-ended emotion recognition task in which they were presented with congruent happy, angry, and fearful DAVE stimuli, one at a time, and asked to supply a label for the emotion conveyed. In this task, accuracy in both groups for each emotion was on average at least 75%, confirming that the forced-choice emotion identification task embedded in the fEMG task might have been particularly difficult. Nevertheless, lower accuracy in identifying fear is consistent with prior research (e.g. Rapcsak, Galper, Comer, Reminger, Nielsen, Kaszniak, Verfaellie, Laguna, Labiner & Cohen, 2000).

Mean activity 500 to 1000 ms post-stimulus onset

To examine whether patterns of corrugator and zygomatic activity to happy, angry, and fearful expressions differed between the groups, we ran a three-way repeated measures ANOVA, with group (ASD, TD) as the between-subjects factor and emotion (happy, angry, fearful) and muscle (corrugator, zygomatic) as within-subject factors. There was a statistical trend toward a group*emotion*muscle interaction, $F(2, 64) = 2.5$, $p = .09$, $\eta^2_p = .07$. Due to the relatively modest sample size in each group, we were likely underpowered to detect this interaction. Thus, as in all previously published fEMG studies in autism, we pursued specific within-group analyses in line with our a priori hypotheses.

The emotion by muscle repeated measures ANOVA for the TD group revealed a significant interaction, indicating differential muscle activity across happy, angry, and fearful stimuli, $F(1.4, 23)^7 = 9.5$, $p = .001$, $\eta^2_p = .37$ (see Figure 1a). Follow-up paired samples *t*-tests indicated that there was a significantly greater increase in zygomatic compared to corrugator activity for happy expressions, $t(16) = 2.6$, $p = .02$, $\eta^2_p = .3$, and a significantly greater increase in corrugator compared to zygomatic activity for fearful expressions, $t(16) = 3.1$, $p = .007$, $\eta^2_p = .38$. There was no significant difference in muscle activity to angry expressions, $t(16) = 0.7$, $p = .49$, $\eta^2_p = .03$.

In contrast, the emotion by muscle interaction was not significant for the ASD group, indicating lack of differentiated fEMG responses to happy, angry, and fearful stimuli, $F(2, 32) = 1.5$, $p = .25$, $\eta^2_p = .08$ (see Figure 1b). Paired samples *t*-tests confirmed that there were no significant differences between zygomatic and corrugator activity to happy, $t(16) = 1.2$, $p = .26$, angry, $t(16) = .32$, $p = .76$, and fearful, $t(16) = .34$, $p = .49$, stimuli in the ASD group (all $\eta^2_p < .1$).

To further examine the pattern of undifferentiated responding in the ASD group, we conducted exploratory

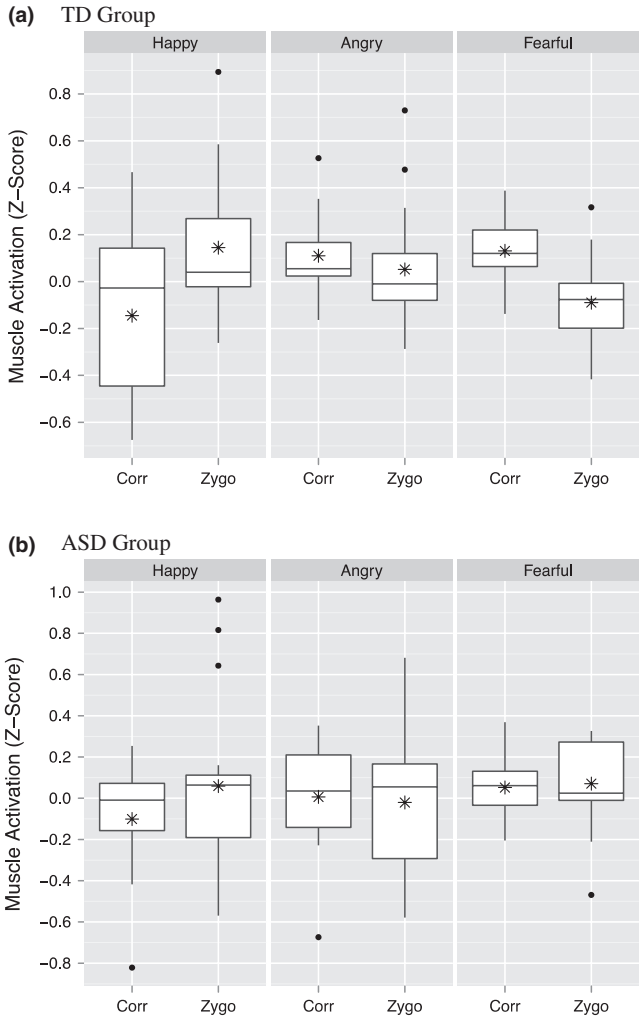

Figure 1 *Mean standardized corrugator and zygomatic activity from 500 through 1000 milliseconds post-stimulus onset for each group. Boxplots should be interpreted as follows: The box reflects the middle 50% of the data, with the horizontal line denoting the median and the asterisk (*) denoting the mean of the variable. The whiskers indicate the minimum and maximum data values, excluding outliers which, when present, are denoted by solid black circles (●).*

analyses to determine the number of individuals in each group who showed a congruent muscle response. For each emotion, we identified *congruent responders*, who showed greater relative activation of the congruent muscle compared to incongruent muscle (i.e. zygomatic>corrugator for happy; corrugator>zygomatic for angry and fearful) and *incongruent responders*, who showed greater relative activation of the incongruent muscle compared to the congruent muscle (i.e. corrugator>zygomatic for happy, zygomatic>corrugator for angry and fearful). The small number of *non-responders*

(who showed muscle suppression of both the corrugator and zygomatic to all stimuli) was combined with incongruent responders.

The proportion of individuals who showed a congruent response was not statistically different between the two groups for happy stimuli (ASD = 47%, TD = 59%), χ^2 (n = 1) = 0.47, p = .49, and angry stimuli (ASD = 35%, TD = 59%), χ^2 (n = 1) = 1.89, p = .17. A significantly lower proportion of individuals in the ASD group showed a congruent response to fearful stimuli compared to the TD group, (ASD = 35%, TD = 82%), χ^2 (n = 1) = 7.77, p = .005.

Peak magnitude through 1300 ms

A three-way repeated measures ANOVA, with group (ASD, TD) as the between-subjects factor and emotion (happy, angry, fearful) and muscle (corrugator, zygomatic) as within-subject factors revealed a significant group*emotion*muscle interaction, $F(2, 64) = 3.9$, p = .03, η^2_p = .11.

The emotion by muscle interaction was significant for the TD group, indicating differential muscle activity across happy, angry, and fearful emotions for peak fEMG response, $F(2, 32) = 10.52$, $p < .0001$, η^2_p = .4 (see Figure 2a). Follow-up analyses with paired samples t-tests indicated that happy expressions elicited significantly greater peak activity of zygomatic than the corrugator, $t(16) = 3.0$, $p < .01$, η^2_p = .36, whereas fearful expressions elicited a significantly greater peak activity in the corrugator compared to zygomatic, $t(16) = 2.6$, $p < .05$, η^2_p = .27. There was no significant difference in zygomatic and corrugator peak activity to angry stimuli, $t(16) = 1.1$, p = .28, η^2_p = .07.

The emotion by muscle interaction was not significant for the ASD group, indicating lack of differentiated peak fEMG muscle activity to happy, angry, and fearful facial expressions of emotion, $F(2, 32) = .80$, p = .46, η^2_p = .05 (see Figure 2b). Paired sample t-tests were conducted to determine whether this undifferentiated responding was observed in each of the respective emotions. There were no statistically significant differences in peak zygomatic and corrugator activity to happy, $t(16) = 1.86$, p = .08, η^2_p = .18, and angry, $t(16) = .62$, p = .54, η^2_p = .02, expressions. However, for fearful expressions, peak zygomatic activity was significantly greater than peak corrugator activity, $t(16) = 2.5$, p = .02, η^2_p = .28.

Time course of fEMG response

In order to further explore the timing and pattern of fEMG activity within each group, we analyzed the time course of corrugator and zygomatic activity to happy, angry, and fearful expressions from 500 ms through 1300 ms post-stimulus onset. Two repeated measures 3 by 8 ANOVAs, one for each muscle, were conducted for each group with emotion and time post-stimulus onset (500–600 ms, 600–700 ms, 700–800 ms, 800–900 ms, 900–1000 ms, 1000–1100 ms, 1100–1200 ms, 1200–1300 ms) as within-subject factors.

In the TD group, the emotion by time interaction was significant for the corrugator, $F(4.5, 71.8)^7 = 3.3$, p = .01, η^2_p = .17, and the zygomatic, $F(6.7, 106.4)^7 = 2.66$,

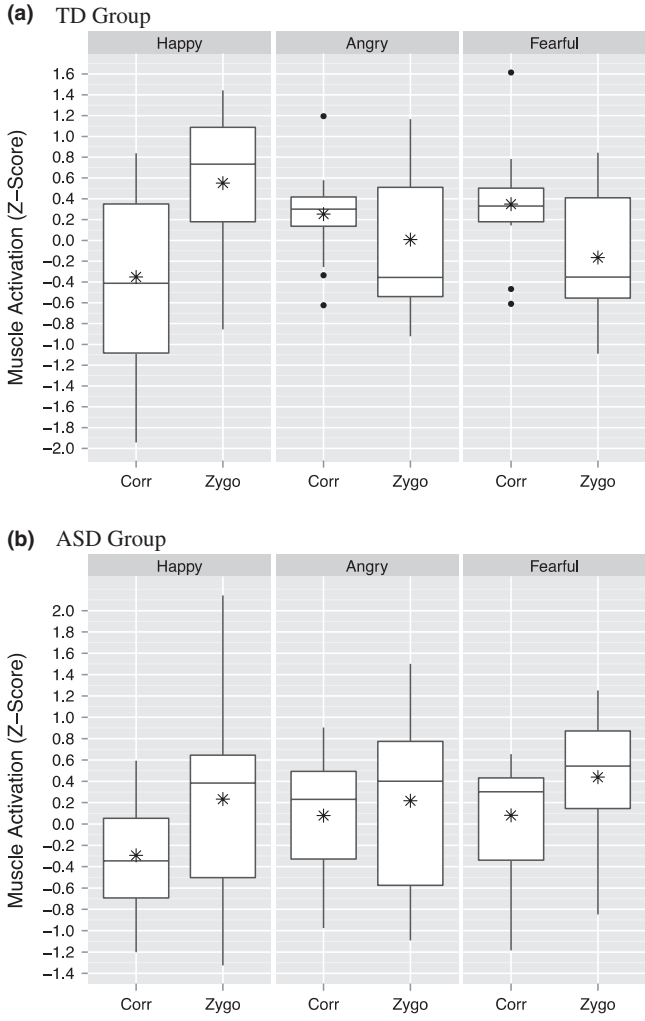

Figure 2 *Mean standardized peak magnitude of corrugator and zygomatic activity through 1300 milliseconds post-stimulus onset for each group. Boxplots should be interpreted as follows: The box reflects the middle 50% of the data, with the horizontal line denoting the median and the asterisk (*) denoting the mean of the variable. The whiskers indicate the minimum and maximum data values, excluding outliers which, when present, are denoted by solid black circles (●).*

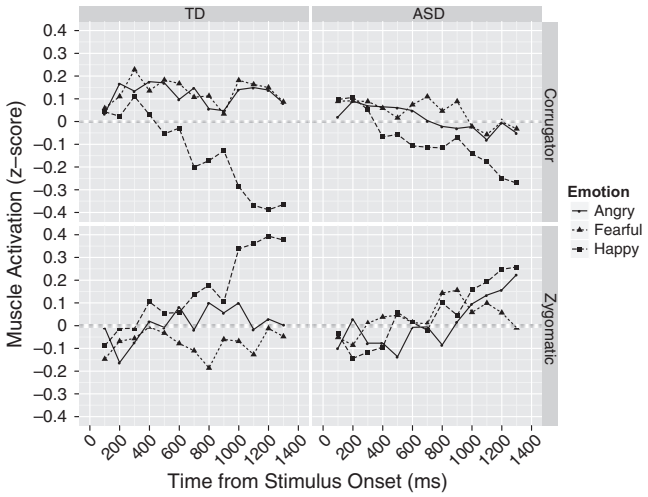

Figure 3 *Time course of standardized EMG activity to happy, angry, and fearful expressions through 1300 milliseconds post-stimulus onset, presented separately by muscle and group.*

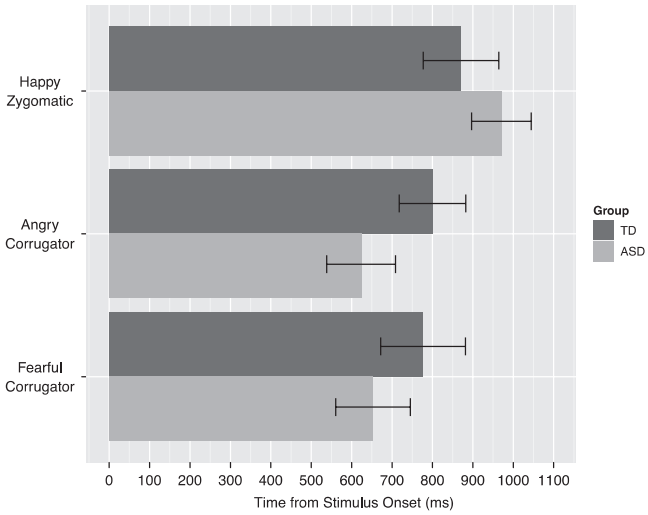

Figure 4 *Average latency of peak response of the zygomatic to happy stimuli and corrugator to angry and fearful stimuli, in milliseconds from stimulus onset, for each group.*

p = .02, η^2_p = .14. (see Figure 3). Follow-up analyses with paired sample t-tests indicated that a pattern of significantly greater activation of the corrugator to angry and fearful stimuli compared to happy stimuli emerged 600 to 700 ms post-stimulus onset and, with the exception of the 800–900 ms period, remained statistically significant through 1300 ms post-stimulus onset (p values .03–.001). Similarly, a pattern of significantly greater activation of the zygomatic to happy compared to fearful stimuli emerged 700–800 ms post-stimulus onset and, with the exception of the 800–900 ms period, remained significant through 1300 ms (p values .001–.005). A significant difference in zygomatic activity between happy and angry stimuli emerged 1000–1100 ms post-stimulus onset and continued through 1300 ms (p values .02–.004).

In the ASD group, the emotion by time interaction was not significant for the corrugator, $F(5.2, 82.9)^7$ = 0.71, p = .62, η^2_p = .04, or the zygomatic, $F(14, 224)^7$ = 1.29, p = .21, η^2_p = .08. As seen in Figure 3, there were largely no significant differences in corrugator and zygomatic activity to happy, angry, and fearful expression across the entire 500–1300 ms period, echoing earlier findings of undifferentiated fEMG responding both within a specific time window post-stimulus onset (500–1000 ms) and for peak magnitude.

Group differences in magnitude and latency to peak

Group by emotion ANOVAs revealed no main effects or interactions involving group on activity on the emotion-congruent muscle, both for average activity level 500–1000 ms post-stimulus onset and for peak response (all ps > .1, all η^2_p < .06). There were no group differences in the magnitude of fEMG response on the zygomatic to happy stimuli, or on the corrugator to angry and fearful stimuli. The group by emotion interaction was also not significant for latency to peak response on the congruent muscle, indicating that the groups did not differ in the timing of the peak response across emotions, $F(2, 64)$ = 1.2, p = .3, η^2_p = .04. There were no group differences in the timing of the peak on the zygomatic for happy expressions nor on the corrugator for angry and fearful expressions (all ps > .1; see Figure 4).

Discussion

We examined fEMG activity to dynamic, audio-visual expressions of positive and negative emotions in individuals with ASD and typically developing controls. Across two different measures of response level, we found a pattern of fEMG activity in the ASD group that was undifferentiated with respect to the valence of the emotional stimulus. Whereas the TD group demonstrated emotion-selective fEMG responses, with greater relative activation of the zygomatic to happy expressions and greater relative activation of the corrugator to fearful expressions, in the ASD group there were no significant differences between zygomatic and corrugator activity to positive and negative emotions, with one exception.[8]

[8] Peak magnitude to fearful stimuli (zygomatic greater than corrugator).

Evidence of lack of selectivity of muscle activation with respect to the valence of the stimulus in the ASD group was further reinforced by exploratory analyses of the time course of fEMG activity, which suggested that the amount of corrugator and zygomatic activity did not differ significantly in response to happy, angry, and fearful stimuli from 500 through 1300 ms post-stimulus onset. Moreover, compared to the TD group, a smaller proportion of individuals in the ASD group showed a congruent response to happy, angry and fearful stimuli, although this difference was statistically significant for the fearful stimuli only.

Individuals with ASD did not differ from TD controls in the magnitude and timing of fEMG responses on the valence-congruent muscle. This indicates that the undifferentiated pattern of muscle activity observed in the ASD group was not due to individuals with autism failing to activate the zygomatic to happy stimuli or the corrugator to angry and fearful stimuli. The picture of fEMG activity to emotional stimuli in ASD that emerges from the present study is not one of a lack of (Beall *et al.*, 2008) or delayed (Oberman *et al.*, 2009) responses, but rather, a subtler one of indiscriminant muscle activation and suppression across happy, angry, and fearful expressions. Follow-up analyses indicated that this pattern was particularly striking during the presentation of fearful stimuli, mirroring Beall and colleagues' (2008) report of undifferentiated responses to static facial expressions of fear in children with ASD.

Our findings dovetail nicely with a classic behavioral study by Yirmiya and colleagues (1989) that reported a higher proportion of emotional blends in the facial expressions of children with autism compared to children with intellectual disability and typically developing children. The researchers used an anatomically based facial affect coding system and found that compared to the other two groups, a larger proportion of children with autism displayed blends of two or more negative emotions (e.g. anger and fear simultaneously) and incongruous blends (composed of both negative and positive affect expressions, such as anger and enjoyment-joy simultaneously). Importantly, children with autism displayed unique blends that were not displayed by any of the children in the other two groups, such as simultaneous displays of fear and interest, anger and joy, and fear and anger. One intriguing possibility is that the Yirmiya findings represent overt facial expressions of the more subtle patterns of simultaneous activation of the corrugator and zygomatic to fearful and angry stimuli detected via fEMG in the present study.

The tendency for individuals with autism in our sample to show zygomatic activity to angry and fearful expressions may be viewed in the context of research on neural substrates of emotion processing in autism. Especially relevant is evidence of hypoactivation of the amygdala during processing of fearful and angry emotional expressions in individuals with ASD (Ashwin, Baron-Cohen, Wheelwright, O'Riordan & Bullmore, 2007; Baron-Cohen, Ring, Wheelwright, Bullmore, Brammer, Simmons & Williams, 1999; Critchley, Daly, Bullmore, Williams, Van Amelsvoort, Robertson, Rowe, Phillips, McAlonan, Howlin & Murphy, 2000). Given the amygdala's involvement in rapid, automatic, and non-conscious processing of emotional stimuli, particularly those involving fear and threat (e.g. Adolphs, Tranel, Damasio & Damasio, 1995; Morris, Frith, Perrett, Rowland, Young, Calder & Dolan, 1996; Pessoa & Adolphs, 2010; Whalen, Rauch, Etcoff, McInerney, Lee & Jenike, 1998), amygdala hypoactivation may be related to the undifferentiated fEMG responses observed in the current study. Most recently, an ERP study reported a lack of differentiation in the face-sensitive N170 component between fearful, angry, and neutral static facial stimuli in children and adolescents with ASD (Wagner, Hirsch, Vogel-Farley, Redcay & Nelson, 2012; see also Dawson, Webb, Carver, Panagiotides & McPartland, 2004). The undifferentiated patterns of facial muscle activity in response to fearful and angry emotional stimuli in our study thus echo neural evidence of disrupted neural processing of negative emotions in ASD.

The pattern of indiscriminate activation of the zygomatic to positive and negative expressions in the current study may also stem from the dynamic, audio-visual nature of the stimuli employed. Individuals with autism show atypical activation of the 'social brain', including the fusiform gyrus (FG), posterior superior temporal sulcus (STS), and amygdala (e.g. Critchley *et al.*, 2000; Castelli, Frith, Happe & Frith, 2002; Dalton *et al.*, 2005), a neural network that is typically differentially recruited during perception of dynamic expressive features (LaBar, Crupain, Voyvodic & McCarthy, 2003; Sato *et al.*, 2004). A recent fMRI study reported reduced activity in the amygdala and FG to dynamic emotional expressions in individuals with autism, and a lack of modulation of the amygdala, FG, and STS by dynamic compared with static emotional expressions (Pelphrey, Morris, McCarthy & LaBar, 2007). Our findings of atypical patterns of fEMG to dynamic emotional displays in autism may thus be tapping into a much broader disruption of neural networks responsible for the processing of dynamic, socio-emotional information.

How might undifferentiated responding to dynamic, audio-visual emotional content in ASD be interpreted in

light of the prevailing theoretical perspectives on the role of facial muscle activity in emotion perception? One such perspective proposes that fEMG activity reflects subtle affective responses to the perceived stimulus, and is thus a result of the observer's emotional state (Cacioppo *et al*., 1988; Dimberg, 1997; Winkielman & Cacioppo, 2001). Researchers subscribing to this perspective point to experimental studies indicating that fEMG responses can initiate and modulate emotional experience and that blocking mimicry selectively impairs recognition of specific emotions (Niedenthal, Brauer, Halberstadt & Innes-Ker, 2001; Oberman *et al*., 2007). One prediction stemming from this proposal is that the affective mechanisms underlying fEMG may not necessarily produce a matching response; for example, an observer may react to an angry stimulus with fEMG activity reflecting a fearful response (Moody *et al*., 2007). In our study, the ASD group appeared to react with zygomatic activity to both positive and negative emotional stimuli, which may suggest a conflicting affective response, or that they may not have been sharing and responding to the emotion in a typical manner. Indeed, zygomatic activity has been observed during exposure not only to the most pleasant images but also, to a lesser degree, to the most unpleasant images. This has primarily been observed during exposure to the more arousing, disgust-eliciting images (Bradley, Codispoti, Cuthberg & Lang, 2001; Larsen, Norris & Cacioppo, 2003) and interpreted to reflect facial grimacing (Bradley & Lang, 2007; Burton, 2001). Elevated zygomatic activity to fearful and angry stimuli in our sample may thus represent a subtle grimace expression as a result of arousal or aversive reaction to the DAVE stimuli, whose emotional impact may have been further enhanced by their dynamic nature (Sato & Yoshikawa, 2007; Weyers, Muhlberger, Hefele & Pauli, 2006). While this interpretation is at present speculative, it is in line with behavioral evidence indicating that individuals with autism may have particular difficulty processing and recognizing negative emotions such as fear (Ashwin, Chapman, Colle & Baron-Cohen, 2006; Howard, Cowell, Boucher, Broks, Mayes, Farrant & Roberts, 2000; Humphreys *et al*., 2007; Pelphrey, Sasson, Reznick, Paul, Goldman & Piven, 2002; Uono, Sato & Toichi, 2011) and anger (Ashwin *et al*., 2006; Giola & Brosgole, 1988). One future direction is to directly examine whether fEMG activity modulates emotional experience in ASD in an effort to clarify whether the pattern of undifferentiated responding documented in the present study may be attributed to disrupted affective processing. Future research also may gather concurrent measures of physiological arousal, such as heart rate and skin conductivity, during stimulus presentation and examine the extent to which emotional arousal covaries with fEMG activity.

Our findings may also be interpreted in light of the proposal that fEMG responses are non-emotional motor reactions that reflect mimicking of the presented stimulus (Chartrand & Bargh, 1999; Hatfield *et al*., 1994), which subsequently generate emotional experience through facial feedback (McIntosh, 1996). This proposal fits within the broader theoretical framework of embodied cognition, whereby an internal re-experiencing of perceived emotional cues of another person via sensory-motor systems facilitates inferences about that person's emotional state (Atkinson & Adolphs, 2005; Niedenthal, 2007). In our study, the presence of zygomatic activity to both positive and negative facial expressions in the ASD group could stem partly from mimicry of the mouth movements present in these dynamic stimuli. Such differences in attending to specific facial features are expected in light of evidence that individuals with autism spend less time looking at the eyes and more time looking at mouths when presented with dynamic social scenes (e.g. Klin, Jones, Schultz, Volkmar & Cohen, 2002; Pelphrey *et al*., 2002), and show significantly more activation of brain areas involved in more conscious and feature-based analysis when presented with images of fearful faces (Ashwin *et al*., 2007). An exploration of the influence of attentional patterns on fEMG response in individuals with ASD via eye tracking is needed to more formally evaluate the extent to which elevated zygomatic activity in the present study may be the result of motor mimicry of mouth movements.

Previous reports of altered activation of putative mirror neuron regions in the brains of children with ASD during action imitation (Dapretto, Davies, Pfeifer, Scott, Sigman, Bookheimer & Iacoboni, 2006; Nishitani, Avikainen & Hari, 2004; Williams & Waiter, 2006) and observation (Dapretto *et al*., 2006; Oberman, Hubbard, McCleery, Altschuler, Ramachandran & Pineda, 2005; Theoret, Halligan, Kobayashi, Fregni, Tager-Flusberg & Pascual-Leone, 2005) may represent a mechanism by which such atypical motor mimicry may then disrupt emotional resonance via facial feedback in ASD (Hermans, van Wingen, Bos, Putman & van Honk, 2009; McIntosh *et al*., 2006). A more nuanced interpretation stems from recent experimental and theoretical work by Hamilton (2008, 2009), which suggests that the mirror neuron system can be fractioned into different pathways, with a separable indirect route for understanding the goal of an action/emulation and a direct route for action planning/mimicry. Hamilton's model proposes that the latter route is compromised in autism, perhaps due to abnormal top-down modulation, leading to altered performance on tasks requiring automatic mimicry (Hamilton, 2008). This model represents a possible account of how disruptions in the MNS may affect

motor mimicry in ASD and thus disrupt subsequent facial feedback mechanisms for the experience of emotion.

The current study is the first to examine fEMG responses to dynamic, audio-visual expressions of emotion among individuals with ASD. As discussed, the pattern of fEMG activity observed is consistent with both affective and motor accounts, leaving open the question of whether individuals with ASD are merely mimicking the facial expressions or whether their fEMG activity reflects an emotional response to these stimuli (or both). Ultimately, in order to fully address this question, experimental paradigms such as the one employed by Moody and McIntosh (2011) are needed, in which fEMG responses to both dynamic emotional and motor only content are directly compared in order to establish the extent to which affective and motor processes are involved.

Our findings partially replicate previous findings using static stimuli (lack of differences in the magnitude of corrugator and zygomatic activity between ASD and TD groups; evidence for undifferentiated responding in the ASD group) while contradicting others (no evidence of absent or delayed responses in the ASD group). Methodological differences across these studies that we were not able to address in the present analyses, such as the nature of the stimuli presented (static pictures versus dynamic audio-visual displays), the length of exposure to the emotional stimulus (25 ms to 8 seconds), and the window of time post-stimulus onset within which fEMG is analyzed may account for these discrepancies. It is increasingly clear that the literature on fEMG during emotion processing in ASD could greatly benefit from standardization of some of these methodological factors. Direct comparisons of fEMG activity to static and dynamic expressions of emotions within more narrow age ranges (e.g. children only, adolescents only) are needed to evaluate the potential impact of stimulus characteristics and developmental effects both on the pattern of fEMG observed within the ASD group, and on the likelihood of detecting differences between individuals with ASD and typically developing control groups.

Another methodological consideration pertains to individual variability, particularly within the ASD group. The great phenotypic heterogeneity within the ASD population is a well-documented fact, and a number of researchers have proposed that subgroups of individuals with autism may be identified based on various behavioral and neurobiological features (Beglinger & Smith, 2001). It may be that group-level analyses of fEMG activity in this and previous research obscured meaningful within-group differences. Indeed, our exploratory analyses revealed that across the happy, angry, and fearful stimuli, a proportion of individuals within the ASD group showed a pattern of greater activation of the congruent relative to the incongruent muscle. One intriguing future research direction is to examine whether subgroups of individuals with autism, for example those fitting Wing and Gould's (1979) social subtypes of aloof, passive, and active-but-odd, show different patterns of fEMG activity in response to emotional stimuli.

Several limitations of our study should be acknowledged, foremost among them the number of participants and trials that had to be dropped from the analyses due to excessive movement. Given the care we took to instruct the participants, the practice runs, and the subsequent monitoring of participants' attention to the task, and the behavioral results, we feel confident that the results of our study were not due to an inappropriate level of task difficulty. The loss of participants due to excessive movement during data collection was not ideal, although we contend that this is not uncommon for research paradigms that require participants to stay still and pay attention for prolonged periods of time, including eye tracking (e.g. Shic, Bradshaw, Klin, Scassellati & Chawarska, 2011) and fMRI (Brem, Halder, Bucher, Summers, Martin & Brandeis, 2009). Currently, there is no standard in the fEMG literature for screening data for movement artifacts, and published studies provide little detail regarding the specific procedures that the various groups use to screen data prior to analysis. It is therefore impossible to surmise how much variability exists across previously published studies in which trials were retained versus dropped from analyses. We adopted rather strict data cleaning procedures to ensure that our analyses focused on spontaneous fEMG responses rather than responses elicited by overt facial movements, which resulted in the loss of trials from participants who were not able to stay sufficiently still during data collection. Perhaps, similar to fMRI research (e.g. Poldrack, Pare-Blagoev & Grant, 2002), mock fEMG procedures should be introduced to desensitize participants to the sensors, train them as to the amount of stillness necessary, and identify those who may not be capable of remaining sufficiently still during data collection.

A final limitation of the present study was the relatively broad age range of the participants. Given evidence of developmental changes in face processing and emotion recognition throughout childhood and adolescence (e.g. de Heering, Rossion & Maurer, 2012; Thomas, De Bellis, Graham & LaBar, 2007), our age range may have obscured within-group differences in fEMG activity. Although preliminary analyses indicated

that the pattern of results did not appreciably change by restricting the sample to those younger than 18 or 13 years of age, the present findings await replication within more narrow age ranges. And of course, a detailed examination of developmental aspects of fEMG in typical and ASD samples is clearly warranted.

In sum, the current study was the first to examine fEMG responses to dynamic, audio-visual expressions of emotion among individuals with ASD and neurotypical controls. Individuals with ASD demonstrated a pattern of atypical fEMG activity that was undifferentiated with respect to the valence of the emotional stimulus, with indiscriminate responding of the zygomatic muscle region to both positive and negative emotion displays. These findings support previous clinical accounts suggesting that the facial expressions of individuals with autism may be difficult to decipher, as well as behavioral studies indicating a higher proportion of emotion blends in the facial expressions of individuals with ASD. We anticipate that yet another pattern of fEMG activity may be predicted for dynamic emotional scenes or imagery, or for real-world social interactions. Although the dynamic audio-visual stimuli are a strength of the current study, future studies could utilize live human interaction to examine even more subtle information that is conveyed in real-life social interactions. Such paradigms, which additionally tap into the reciprocal nature of these interactions, are ultimately needed to truly understand the role that atypical fEMG activity may play in the difficulties individuals with ASD encounter with processing emotions in their day-to-day lives.

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