

Facial electromyographic responses to emotional information from faces and voices in individuals with pervasive developmental disorder

Maurice J.C.M. Magnée,^{1,2} Beatrice de Gelder,^{2,4} Herman van Engeland,¹ and Chantal Kemner^{1,3}

¹Rudolf Magnus Institute of Neuroscience, Department of Child and Adolescent Psychiatry, University Medical Center Utrecht, The Netherlands; ²Laboratory of Cognitive and Affective Neuroscience, Tilburg University, The Netherlands; ³Section Biological Developmental Psychology, Faculty of Psychology, Maastricht University, The Netherlands; ⁴Martinos Center for Biomedical Imaging, Massachusetts General Hospital and Harvard Medical School, USA

Background: Despite extensive research, it is still debated whether impairments in social skills of individuals with pervasive developmental disorder (PDD) are related to specific deficits in the early processing of emotional information. We aimed to test both automatic processing of facial affect as well as the integration of auditory and visual emotion cues in individuals with PDD. **Methods:** In a group of high-functioning adult individuals with PDD and an age- and IQ-matched control group, we measured facial electromyography (EMG) following presentation of visual emotion stimuli (facial expressions) as well as the presentation of audiovisual emotion pairs (faces plus voices). This emotionally driven EMG activity is considered to be a direct correlate of automatic affect processing that is not under intentional control. **Results:** Our data clearly indicate that among individuals with PDD facial EMG activity is heightened in response to happy and fearful faces, and intact in response to audiovisual affective information. **Conclusions:** This study provides evidence for enhanced sensitivity to facial cues at the level of reflex-like emotional responses in individuals with PDD. Furthermore, the findings argue against impairments in crossmodal affect processing at this level of perception. However, given how little comparative work has been done in the area of multisensory perception, there is certainly need for further exploration. **Keywords:** Autism, emotional processing, facial expressions, voice prosody, electromyography (EMG), multisensory perception.

Pervasive developmental disorder (PDD) refers to a group of DSM-IV developmental disorders of which childhood autism is the most severe (American Psychiatric Association, 1994). It is characterized by qualitative deficits in social interaction and communication and by stereotyped, repetitive behaviors. Among the most characteristic interactional impairments is the lack of social and emotional reciprocity. In his original work on the syndrome of childhood autism, Kanner (1943) already mentioned the children's 'innate inability to form the usual, biologically provided affective contact with people'. Over 60 years of research on this topic has not yet uncovered what factors are underlying this typical inability. However, recent advances in cognitive neuroscience are progressively increasing our knowledge about human emotions. Emerging topics of interest are, among others, the functional role of motor behavior in the processing of emotional stimuli and the integration of emotional information from different sensory modalities, like for instance from the face and the voice.

One way to study the motor correlates of emotional stimuli is by measuring facial electromyography (EMG) to these stimuli. It is well known from EMG studies that viewing facial expressions generates subtle changes in an observer's facial muscle activity. Such changes are seldom visible to the naked eye, but EMG can reliably measure them. Specifically, viewing happy faces elicits increased *zygomaticus major* activity, whereas negative stimuli (e.g., angry faces) spontaneously evoke increased *corrugator supercilii* muscle activity (Dimberg, 1982). *Corrugator supercilii* moves the brows down into a frown and *zygomaticus major* elevates the cheeks and pulls the corners of the mouth back and upwards into a smile. These effects are also observed when the participants are not aware that they see a facial expression, as when the visual stimulus is masked (Dimberg, Thunberg, & Elmehed, 2000). Furthermore, similar facial reactions are observed when subjects observe stimuli other than facial expressions, such as vocal affect expressions (Hietanen, Surakka, & Linnankoski, 1998), and emotional body postures (Magnée, Stekelenburg, Kemner, & de Gelder, 2007). This facial motor

Conflict of interest statement: No conflicts declared.

© 2007 The Authors

Journal compilation © 2007 Association for Child and Adolescent Mental Health.

Published by Blackwell Publishing, 9600 Garsington Road, Oxford OX4 2DQ, UK and 350 Main Street, Malden, MA 02148, USA

behavior is therefore not an instance of strict mimicry of the stimulus, but can be considered as a fundamental component in the process of automatic emotion perception (Hatfield, Cacioppo, & Rapson, 1994).

Several researchers have argued that the lack of emotional reciprocity among individuals with PDD is a consequence of impaired recognition of emotional expressions and gestures, and of dysfunctions in the ability to appropriately modify their behavior in response to emotional cues of others (see for review Bachevalier & Loveland, 2006). Despite a large number of studies investigating facial expression recognition in PDD, however, the extent of the deficit is not clear. The variability across studies is striking and several studies have failed to find an impairment altogether (e.g. Gepner, Deruelle, & Grynfeldt, 2001; Loveland et al., 1997; Ozonoff, Pennington, & Rogers, 1990). One explanation for these mixed findings might be that patients can acquire compensational strategies, which means that more refined research methods are required to detect possible deficits (de Gelder, 1987). For instance, recent behavioral evidence using morphed continua of facial expressions points towards a specific deficit in the recognition of fear (Humphreys, Minshew, Leonard, & Behrmann, 2007), which has also been found in other studies (e.g. Ashwin, Baron-Cohen, Wheelwright, O'Riordan, & Bullmore, 2007; Dawson, Webb, Carver, Panagiotides, & McPartland, 2004). Unraveling the close link between processing of emotions in the face and activation of emotion-related motor activity might shed more light on what is underlying the lack of emotional reciprocity in PDD.

Furthermore, since the same pattern of EMG reactivity is found in response to facial and to vocal affect expressions, it is possible to evaluate what the voice contributes to the motor response when combined with the face, i.e. the effect of the integration of emotional cues. The early integration of emotional stimuli from the auditory and visual modality is an important mechanism in producing rapid adaptive responses (e.g. de Gelder, Böcker, Tuomainen, Hensen, & Vroomen, 1999), and therefore relevant to studies on PDD. Difficulties with integration of information across different sensory modalities have been suggested in the literature as an important problem in PDD (see for review Iarocci & McDonald, 2006). Evidence for deficits in crossmodal perception of emotions in PDD, however, is to date surprisingly limited. In one of the few studies on this topic, Hobson (1986) found impaired behavioral performance in an autistic group, although this could not be replicated (Prior, Dahlstrom, & Squires, 1990). In a PET study, Hall, Szechtman, and Nahmias (2003) found a pattern of cerebral blood flow in individuals with PDD that indicated less emphasis on an integrated processing of emotional stimuli than controls during the perception of facial expressions

accompanied by prosodic information. However, given the scarce number of studies and unequivocal results, further research is required to understand the role of crossmodal integration in emotion processing in PDD.

In a recent crossmodal EMG study in healthy controls, facial muscle responses were measured while participants observed happy and fearful face-voice pairs, which were either emotionally congruent or incongruent (Magnée et al., 2007). The results clearly indicated increased reactivity to congruent as compared to incongruent affective stimulation. Specifically, congruent fearful face-voice pairs evoked corrugator activity, while congruent happy face-voice pairs evoked zygomaticus responses. This paradigm of crossmodal bias is known to provide evidence for multisensory perception, as it measures how processing in one modality is influenced by information presented in the other modality. It has been shown that these crossmodal bias effects take place at an early perceptual level (de Gelder et al., 1999), independent of awareness of the face stimulus (de Gelder, Pourtois, & Weiskrantz, 2002).

The objective of the present study was to investigate visual and combined visual and auditory affect processes in a group of young adults with PDD, by taking electromyographic measures of zygomaticus major and corrugator supercilii. Facial EMG responses were measured during the presentation of emotionally congruent and incongruent face-voice stimulus pairs. In line with previous data, we hypothesized that visual presentation of a happy face would in the control group lead to increased zygomaticus activity compared to viewing of a fearful face, and the presentation of a fearful face would lead to increased corrugator activity compared to viewing of a happy face. Also, we hypothesized that for the congruent stimulus pairs, happy face-voice trials would lead to increased zygomatic muscle activity and fearful face-voice trials to increased corrugator activity, compared with emotionally incongruent stimuli. For the individuals with PDD, increases in facial muscle activity in response to facial expressions would give evidence for intact reflex-like emotional motor activity. Additionally, finding increased facial muscle responses to congruent audiovisual (AV) expressions would suggest an intact integration of visual and auditory affective processes.

Methods

Participants

Thirteen high-functioning, medication-free, adult males with PDD (average age 21.5, SD 4.0) and 13 healthy adult males (average age 23.0, SD 2.9) participated in the study. All individuals were administered the Wechsler Adult Intelligence Scale, Dutch edition (WAIS-III-NL). Mean age and total IQ scores were similar for individuals with PDD (IQ 122.4, SD 9.2) and individuals

Table 1 ADI-R & ADOS scores in the PDD group

	Mean (SD)	Cut-off scores
ADI Social behavior	19.2 (3.5)	10
ADI Communication	14.9 (5.3)	8
ADI Repetitive behaviors	5.5 (3.2)	3
ADI Age of onset	2.7 (1.1)	1
ADOS Communication	4.1 (1.7)	2
ADOS Social behavior	8.9 (3.8)	4

from the control group (IQ 127, SD 14.4). Before individuals were administered to the control group they were screened for neurological and psychiatric history, and for familial history of psychiatric disorders using a short questionnaire.

All diagnoses of PDD (either autistic disorder or Asperger syndrome) were based on DSM-IV criteria and were made by a child psychiatrist. Additionally, all patients were administered the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1989) by a trained rater, and their parents were informants on the Autism Diagnostic Interview Revised (ADI-R; Lord, Rutter, & Le Couteur, 1994). Seven individuals with PDD met full ADI-R and ADOS criteria for autism or autism spectrum disorder. We were not able to acquire ADOS scores for two patients, but both fulfilled ADI-R criteria. Three individuals met criteria on the ADOS and scored one or two points below cutoff on one scale of the ADI-R. One individual scored one point below cutoff on both ADI-R (stereotyped behavior) and ADOS (social behavior) criteria (see Table 1 for group averages).

All participants had normal or corrected to normal vision. They were all paid for participation. Written informed consent was obtained for each participant before the session, according to the Declaration of Helsinki (2000). Approval of the medical ethics committee of the University Medical Center Utrecht was obtained prior to the study.

Stimuli and procedure

Visual stimuli consisted of six happy and six fearful faces (half male) taken from the Ekman series (Ekman & Friesen, 1976). Auditory stimuli consisted of spoken sentence fragments with a neutral content, which were pronounced in either a happy or fearful tone of voice (the Dutch sentence fragment 'met het vliegtuig' meaning 'by plane'). Each visual stimulus was combined with a spoken fragment in order to construct audiovisual stimulus pairs with either a matched (congruent) or a mismatched (incongruent) affective content, resulting in 12 congruent and 12 incongruent stimulus pairs. The face-voice pairings were the same throughout the experiment such that one face identity was always paired with the same voice identity.

The size of the portraits was 19 cm high × 13 cm wide, which at the mean viewing distance of 80 cm corresponds to a visual angle of 13.5° × 9.2°. The mean luminance of the pictures was 38 cd/m² on a 2.5 cd/m² background. Sound was delivered over one loudspeaker placed directly below the screen at a mean sound level of 60 dB(a).

A trial always started with the presentation of the face. After 900 ms, the auditory stimulus was presen-

ted, whereas the face remained on screen until the end of the voice fragment. This delay was introduced to be able to analyze the visual and the AV EMG response separately. The six resulting stimulus categories were as follows: visual happy, visual fear, congruent AV happy, congruent AV fear, incongruent auditory happy-visual fear and incongruent auditory fear-visual happy. Participants were comfortably seated in a chair in a soundproof experimental chamber. They were instructed to judge the sex of each stimulus pair, by pushing one of two designated buttons on a response box. To avoid any response-related components in the ongoing EMG signal, they were instructed not to respond until after offset of the visual stimulus. Intertrial interval was chosen randomly between 1000 and 1500 ms, immediately after the participant's response. During this interval, a central fixation cross was presented on screen. Stimuli within a total of eight blocks of 24 AV trials (equal amount of congruent and incongruent stimuli) were presented randomly.

Recordings

Bipolar EMG activity was recorded from two left facial muscles (zygomaticus major and corrugator supercilii), following the guidelines given by Fridlund and Cacioppo (1986). On each muscle, two Ag/AgCl flat-type active electrodes (BIOSEMI) with a contact area of 2 mm and casing of 11 mm diameter were placed in a direction parallel to the muscle and with a distance of 15 mm between electrode centers.

During recording, EMG signals were filtered (DC–134 Hz, –3 dB) at a sample rate of 512 Hz. Subsequently, EMG signals were filtered offline (high-pass 20 Hz, 48 dB/octave), full wave rectified and checked for gross movement associated with irrelevant activities. The raw data were segmented into epochs for visual and AV categories separately. The two visual stimulus categories consisted of a 500-ms pre-stimulus baseline condition and a 900-ms visual stimulus condition. The four AV-stimulus categories consisted of similar 500-ms pre-stimulus and 900-ms visual conditions, and an extra 900-ms AV-stimulus condition. For the two visual-stimulus categories, mean rectified EMG amplitudes were calculated for the 900-ms visual-stimulus conditions. The AV categories contained mean rectified-EMG amplitude for the 900-ms AV stimulus conditions. Subsequently, these data points were depicted as a percentage of the mean pre-stimulus baseline amplitude.

Two separate multivariate analyses of variance (MANOVA) were performed (visual and AV) for each muscle region, to test how the activity of the two muscles was affected by stimulus category and whether there were differences in this respect between groups. MANOVA analyses for the visual EMG consisted of one between-subjects factor Group with two levels (PDD and control group) and one within-subjects factor Emotion with two levels (happy and fear). In the AV conditions, we tested separately for corrugator and zygomaticus whether EMG activity in response to congruent and incongruent AV stimuli differed from each other, using one between-subjects factor Group with two levels (PDD and control group) and the two within-subject factors Emoface (happy face vs. fearful face) and Emovoice (happy voice

vs. fearful voice). A significant interaction between the two variables can be decomposed into the specific contrast effects in which the effect of congruency is tested. For corrugator muscle, congruency effects across both groups are measured for congruent fearful face–voice pairs compared with the incongruent fearful face–happy voice pairing. For zygomaticus muscle, the congruent happy face–voice condition is tested against incongruent happy face–fearful voice. To control for possible differences in baseline muscle activity we conducted independent-samples *t*-tests based on the 500-ms pre-stimulus baseline conditions, separate for each muscle and stimulus condition.

Results

For the corrugator supercillii and zygomaticus major muscles, the facial EMG reactions to visual stimuli are presented in Figure 1. Presentation of a fearful face significantly increased corrugator activity more than presentation of a happy face in both groups, $F(1,24) = 10.85$, $p < .01$. The two groups did not differ in this effect, as there was no significant Emotion * Group interaction. However, although no group interaction was found in the difference between corrugator responses to happy and fearful faces, corrugator activity to fearful faces only could be informative regarding possible sensitivity to

negative stimuli among individuals with PDD. To test this hypothesis, we continued with an independent-samples *t*-test comparing percentage of corrugator activity for fearful faces between both groups. Specifically, mean (\pm SE) percentage of corrugator activity compared with baseline was significantly larger in the PDD group ($106.9\% \pm 2.2$) than among healthy controls ($103.7\% \pm .9$), $t(24) = -1.3$, $p < .05$.

Zygomaticus major activity was more pronounced in response to the presentation of happy compared to fearful facial expressions across both groups, $F(1,24) = 18.85$, $p < .001$. The analysis furthermore revealed a significant Group * Emotion interaction, $F(1,24) = 5.08$, $p < .05$. Decomposing this interaction in the specific effect of Emotion for both groups separately revealed significant main effects in both the PDD group ($F(1,12) = 13.46$, $p < .01$) and the control group ($F(1,12) = 5.67$, $p < .05$). To specifically test whether the difference in zygomatic response between happy and fearful faces was indeed larger in the PDD group, we calculated this difference for both groups. An independent-samples *t*-test surprisingly showed that the difference in zygomatic response was significantly larger for the PDD group (mean \pm SE difference $8.4\% \pm 2.3$) than for the control group ($2.6\% \pm 1.1$), $t(24) = -2.25$, $p < .05$. As can be seen from Figure 1B, in both groups zygomaticus activity was clearly reduced in response to fearful faces compared with activity during baseline (mean (\pm SE) for control group was $96.3\% \pm 1.0$, for PDD group $92.7\% \pm 1.7$). A between-group comparison using an independent-samples *t*-test revealed that this inhibitory effect of stimulus presentation on zygomaticus activity was not significantly different between the two groups, $t(24) = 1.8$, $p = \text{NS}$.

Facial EMG reactions to AV stimulus pairs are shown in Figures 2 and 3. Across both groups, corrugator muscle responses revealed a marginally significant effect of Emoface, $F(1,24) = 3.46$, $p = .08$, and a significant effect of Emovoice, $F(1,24) = 6.27$, $p < .05$. The interaction between Emoface and Emovoice was also significant, $F(1,24) = 4.52$, $p < .05$. No significant interactions with group were found (all $F < 1$). Decomposing the Emoface * Emovoice interaction into an analysis of specific congruency effects across both groups revealed that corrugator muscle activity was significantly increased in response to congruent fearful face–voice pairs, $F(1,24) = 10.49$, $p < .01$, as compared to the incongruent fearful face–happy voice pairing. Again, this effect was similarly observed in both groups (no significant Congruency * Group interaction; $F < 1$). Note that this increase in corrugator activity is absent when a fearful voice was added to a happy face (Figure 2).

Likewise, analyses of AV stimuli on zygomatic muscle activity revealed no significant effect of Emoface and a marginally significant effect of Emovoice, $F(1,24) = 3.69$, $p = .07$. The interaction between Emoface and Emovoice was significant,

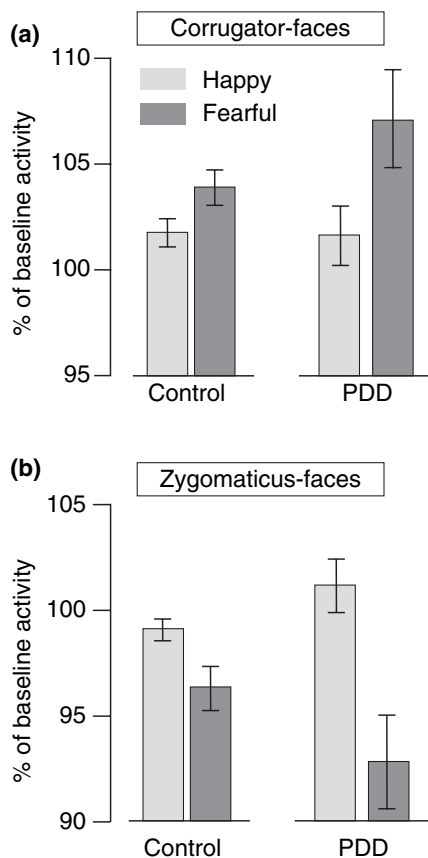


Figure 1 Percentage corrugator and zygomaticus activity (\pm SE) compared to baseline in response to happy and fearful faces

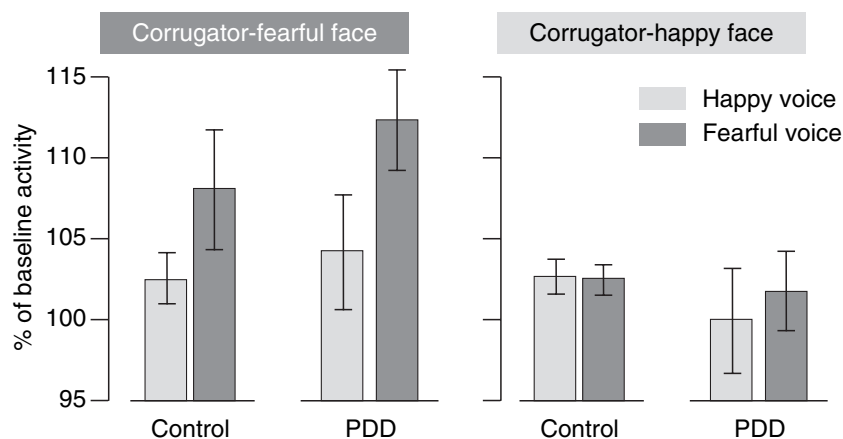


Figure 2 Percentage corrugator activity (+ SE) compared to baseline after happy and fearful voices. Left panel represents corrugator activity when auditory information is added to a fearful face; right panel shows corrugator activity when auditory information is added to a happy face

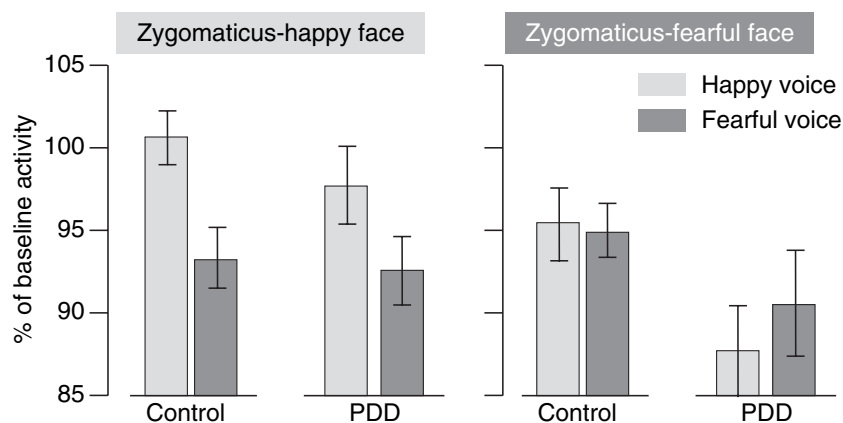


Figure 3 Percentage zygomaticus activity (+ SE) compared to baseline after happy and fearful voices. Left panel represents zygomaticus activity when auditory information is added to a happy face; right panel shows zygomaticus activity when auditory information is added to a fearful face

$F(1,24) = 11.87, p < .01$. No interactions were found between groups (all $F < 1$). Analyzing the specific congruency effects revealed significant increases in response to congruent happy face–voice pairs compared to incongruent happy face–fearful voice pairs across both groups, $F(1,24) = 21.87, p < .01$, with no significant Congruency * Group interaction ($F < 1$). Again, this increase in zygomaticus activity was not found when a happy voice was coupled to a fearful face (Figure 3).

There were no differences in baseline facial muscle activity between the groups for zygomaticus prior to presentation of happy faces, $t(24) = -.37, p = \text{NS}$, and fearful faces, $t(24) = -.34, p = \text{NS}$; and for corrugator prior to presentation of happy faces, $t(24) = 1.02, p = \text{NS}$, and fearful faces, $t(24) = 1.12, p = \text{NS}$.

Discussion

Electromyographic (EMG) responses of facial muscles to visual and combined visual and auditory affective stimuli were measured in high-functioning adult individuals with PDD and matched controls.

With regard to responses to unimodal visual stimuli, we observed that the presentation of a fearful face resulted in more corrugator activity compared to viewing of a happy face, while zygomatic muscle activity was more pronounced in response to viewing of a happy compared to a fearful facial expression, in both the control group as well as the PDD group. However, we did find differences between both groups in the facial muscle responses. Surprisingly, individuals with PDD showed a *larger* difference in zygomatic activity in response to happy versus fearful faces than the control group. Moreover, we found *larger* corrugator responses to the presentation of fearful faces, but not to happy faces in the PDD group.

Furthermore, with regard to emotion-congruent AV conditions, there were emotion specific increases in facial muscle activity for both the control group and the PDD group. The AV fearful face–voice pairs showed increased corrugator activity and AV happy face–voice pairs showed increased zygomatic muscle activity, in comparison with emotionally incongruent face–voice pairs. In short, at the level of reflex-like emotional motor responses we find heightened EMG

responsiveness to facial expressions and normal integration of AV emotional stimuli in individuals with PDD.

While the link between emotion and motor activity is a classical theme in the emotion literature, the interpretation about their relation is still a matter of debate. The discovery of mirror neurons in humans has recently revived the debate on the role of motor structures in emotion perception and has led to the suggestion that the 'mirror neuron system' (MNS) plays a fundamental role in social cognition (Gallese, Keysers, & Rizzolatti, 2004). Mirror neurons are a group of neurons, originally identified in the premotor cortex (area F5) of the macaque, that discharge during action execution as well as when these same actions are observed in others (Rizzolatti et al., 1996). Functional neuroimaging provides evidence for the presence of a MNS in humans, consisting of a network of brain areas involving the ventral premotor cortex area F5 and parietal area 7b (Rizzolatti, Fogassi, & Gallese, 2001). Recent speculations hypothesize that similar 'mirror matching mechanisms' may also be active during higher order cognitive processes, such as theory of mind (Gallese & Goldman, 1998), language (Rizzolatti & Arbib, 1998) and empathy (Gallese, 2003). Both the imitation and the observation of emotional expressions may recruit the MNS, together with brain structures known to be associated with emotional processing, such as the amygdala and insula (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003). Given the lack of emotional reciprocity among individuals with PDD and the suggested deficits in imitating facial expressions (Hertzog, Snow, & Sherman, 1989), a growing number of studies now suggest that dysfunctions in the MNS are involved in the generation of the disorder (e.g. Dapretto et al., 2006; Williams et al., 2006). However, direct evidence for the role of the MNS in the perception of emotions is still very limited and some of the available evidence indirectly speaks against this view. As a matter of fact, in healthy individuals the same emotion-related EMG effects are observed in response to emotional faces (Dimberg, 1982), vocal affect expressions (Hietanen et al., 1998) and emotional body postures (Magnée et al., 2007). This argues against the possibility that this emotion-specific facial muscle reaction is based on mimicry of the stimulus presented, and by the same token it also argues against the notion that imitation is the crucial component in automatic emotion perception as suggested by mirror neuron theorists (Gallese, 2003). In line with this, we suggest that the motor activity as measured in the present study may be triggered in brain centers that can function relatively independently from experiencing the emotional significance. Recent literature points to the amygdala as a brain structure that is particularly involved in grasping the emotional significance of stimuli (de Gelder, 2006).

Numerous studies have suggested a central role for the amygdala in processing of facial expressions, especially fear (Morris et al., 1998). Various functional MRI studies among individuals with PDD have reported deficits in amygdala functioning during perception of facial expressions (e.g., Ashwin et al., 2007; Critchley et al., 2000). On the other hand, these studies contrast with findings by Dalton and colleagues (2005), who found greater activation in the left amygdala of their autistic subjects than matched controls in response to facial stimuli, both emotional and non-emotional. Furthermore, amygdala activation was positively correlated with the amount of eye gaze, indicating that eye fixation and not the emotional content of the face is associated with a heightened emotional response in the patients.

The present finding of increased physiological responsiveness in individuals with PDD to the presentation of facial stimuli is consistent with the Dalton study (2005). Since we did not find differences in baseline muscle activity between the healthy participants and patients, group differences in facial muscle activity were solely the result of the presentation of facial expressions. Therefore, our data suggest that individuals with PDD show a heightened emotional motor response related to facial stimuli, both happy and fearful. Different results, however, were found in a recent EMG study by McIntosh, Reichmann-Decker, Winkielman, and Wilbarger (2006), who found clear deficits in spontaneous EMG responses to happy and angry faces in a group of individuals with PDD. Although there were several methodological differences between the studies (angry instead of fearful faces; blocked instead of randomized stimulus presentation; differences in stimulus duration, response windows and artifact correction), the most important difference may be the instructions used. In our study the task of the participant was to judge the sex of each facial picture, while in the McIntosh study instructions were to passively 'watch the pictures as they appear on the screen'. The Dalton study clearly stated that attention to the (eyes in the) face is of crucial importance in finding increased responses in the patient group, and the active task demands used in our study may have triggered this. The use of short stimulus duration and intervals might have further increased the attentional load that had to be given to the face.

While our finding of increased EMG reactivity to emotional expressions in individuals with PDD is consistent with amygdala dysfunction, the relationship with their problems in social interaction is not entirely clear. One possibility is that it is related to avoidance of social interaction. For instance, measuring electrodermal activity in a group of children with autism, Hirstein, Iversen, and Ramachandran (2001) showed that almost all autistic children had significantly higher electrodermal activity than a group of matched controls. They argued that in order

to control for this hyperactivation, the patients develop a kind of homeostasis-driven behavior, such as the typical gaze avoidance. Our findings could reflect the same compensational mechanism.

Because the same EMG responses are observed to emotions present in faces and voices, we were able to investigate whether deficits in the patients' social behavior may be due to impairments in processing information from multiple channels. Several brain imaging and electrophysiological studies of cross-modal emotion perception in healthy subjects have clearly demonstrated amplification of the neural signal during emotionally congruent AV perception. Dolan, Morris, and de Gelder (2001), for instance, observed increases in amygdala activation when fearful faces were accompanied by fearful voices. The suggestion by Dolan and colleagues that the amygdala is important for emotional crossmodal integration might be directly related to increases in facial muscle activity in response to congruent AV information, as the amygdala is also highly prone to be involved in triggering the automatic facial expressions (Fanardjian & Manvelyan, 1987).

Research on crossmodal integration of emotional information in individuals with PDD, however, to date displays conflicting results (Hall et al., 2003; Hobson, 1986; Prior et al., 1990). The present study argues against impairments in AV processing of affective information at the level of reflex-like motor responses in PDD. This is evidenced by the fact that both groups show increased emotion specific facial muscle activity to emotionally congruent stimuli. Intact facial muscle responses in the patient group indicate that the reflex-like emotional responses, involving connections of amygdala to motor structures and brain stem nuclei, are intact.

In the present study all the participants were young adults with high IQ; therefore further research is needed to establish whether the present results can be generalized to a younger population or to individuals with PDD suffering from intellectual disabilities. Furthermore, since we did not measure EMG responses to non-emotional faces, we cannot conclude whether the effects are specific for the emotional content presented in the face. Generalization of the results therefore should be investigated. The failure to replicate the McIntosh study shows that subtle differences in task design or stimuli used may have a major impact on the results. Thorough investigation of the factors that influence the EMG effects therefore seems necessary.

Conclusion

Taken together, the present results indicate that the reaction to happy and fearful facial stimuli as measured by facial EMG is enhanced among individuals with PDD. These findings might point to heightened physiological re-activity to these stimuli. Further-

more, EMG responses to combined visual and auditory affective stimuli are intact, indicating normal integration of emotional information from faces and voices in the PDD group at least at the level of reflex-like emotional motor responses. However, further research is required to clarify the relation between this automated motor reaction and the deficits of individuals with PDD in social interaction.

Acknowledgements

This research was funded by an Innovational Research Incentives grant of the Netherlands Organization for Scientific Research (NWO; VIDI-scheme, 402-01-094) to Chantal Kemner.

Correspondence to

Maurice Magnée, Department of Child and Adolescent Psychiatry, University Medical Center Utrecht, B01.201, Heidelberglaan 100, 3584 CX Utrecht, The Netherlands; Tel: + 31 30 250 6026; Fax: + 31 30 250 5444; Email: M.J.C.M.Magnee@umcutrecht.nl

References

- American Psychiatric Association. (1994). *Diagnostic and statistical manual of mental disorders*, 4th edn. Washington DC: American Psychiatric Association.
- Ashwin, C., Baron-Cohen, S., Wheelwright, S., O'Riordan, M., & Bullmore, E.T. (2007). Differential activation of the amygdala and the 'social brain' during fearful face-processing in Asperger Syndrome. *Neuropsychologia*, 45, 2–14.
- Bachevalier, J., & Loveland, K. (2006). The orbitofrontal-amygdala circuit and self-regulation of social-emotional behavior in autism. *Neuroscience and Biobehavioral Reviews*, 30, 97–117.
- Carr, L., Iacoboni, M., Dubeau, M.C., Mazziotta, J.C., & Lenzi, G.L. (2003). Neural mechanisms of empathy in humans: A relay from neural systems for imitation to limbic areas. *Proceedings of the National Academy of Sciences of the United States of America*, 100, 5497–5502.
- Critchley, H.D., Daly, E.M., Bullmore, E.T., Williams, S.C., Van Amelsvoort, T., Robertson, D.M., Rowe, A., Phillips, M., McAlonan, G., Howlin, P., & Murphy, D.G. (2000). The functional neuroanatomy of social behaviour: Changes in cerebral blood flow when people with autistic disorder process facial expressions. *Brain*, 123, 2203–2212.
- Dalton, K.M., Nacewicz, B.M., Johnstone, T., Schaefer, H.S., Gernsbacher, M.A., Goldsmith, H.H., Alexander, A.L., & Davidson, R.J. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nature Neuroscience*, 8, 519–526.
- Dapretto, M., Davies, M.S., Pfeifer, J.H., Scott, A.A., Sigman, M., Bookheimer, S.Y., & Iacoboni, M. (2006). Understanding emotions in others: Mirror neuron dysfunction in children with autism spectrum disorders. *Nature Neuroscience*, 9, 28–30.

- Dawson, G., Webb, S.J., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science*, 7, 340–59.
- de Gelder, B. (1987). On not having a theory of mind. *Cognition*, 27, 285–90.
- de Gelder, B. (2006). Towards the neurobiology of emotional body language. *Nature Reviews Neuroscience*, 7, 242–249.
- de Gelder, B., Böcker, K.B., Tuomainen, J., Hensen, M., & Vroomen, J. (1999). The combined perception of emotion from voice and face: Early interaction revealed by human electric brain responses. *Neuroscience Letters*, 260, 133–136.
- de Gelder, B., Pourtois, G., & Weiskrantz, L. (2002). Fear recognition in the voice is modulated by unconsciously recognized facial expressions but not by unconsciously recognized affective pictures. *Proceedings of the National Academy of Sciences of the United States of America*, 99, 4121–4126.
- Dimberg, U. (1982). Facial reactions to facial expressions. *Psychophysiology*, 19, 643–647.
- Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science*, 11, 86–89.
- Dolan, R.J., Morris, J.S., & de Gelder, B. (2001). Crossmodal binding of fear in voice and face. *Proceedings of the National Academy of Sciences of the United States of America*, 98, 10006–10010.
- Ekman, P., & Friesen, W.V. (1976). *Pictures of facial affect*. Palo-Alto, CA: Consulting Psychologists Press.
- Fanardjian, V.V., & Manvelyan, L.R. (1987). Mechanisms regulating the activity of facial nucleus motoneurons-III. Synaptic influences from the cerebral cortex and subcortical structures. *Neuroscience*, 20, 835–843.
- Fridlund, A.J., & Cacioppo, J.T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, 23, 567–589.
- Gallese, V. (2003). The roots of empathy: The shared manifold hypothesis and the neural basis of intersubjectivity. *Psychopathology*, 36, 171–180.
- Gallese, V., & Goldman, A. (1998). Mirror neurons and the simulation theory of mind-reading. *Trends in Cognitive Sciences*, 2, 493–501.
- Gallese, V., Keysers, C., & Rizzolatti, G. (2004). A unifying view of the basis of social cognition. *Trends in Cognitive Sciences*, 8, 396–403.
- Gepner, B., Deruelle, C., & Grynfeltt, S. (2001). Motion and emotion: A novel approach to the study of face processing by young autistic children. *Journal of Autism and Developmental Disorders*, 31, 37–45.
- Hall, G.B.C., Szechtman, H., & Nahmias, C. (2003). Enhanced salience and emotion recognition in autism: A PET study. *American Journal of Psychiatry*, 160, 1439–1441.
- Hatfield, E., Cacioppo, J.T., & Rapson, R.L. (1994). *Emotional contagion*. Cambridge: Cambridge University Press.
- Hertzog, M.E., Snow, M.E., & Sherman, M. (1989). Affect and cognition in autism. *Journal of the American Academy of Child and Adolescent Psychiatry*, 28, 195–199.
- Hietanen, J.K., Surakka, V., & Linnankoski, I. (1998). Facial electromyographic responses to vocal affect expressions. *Psychophysiology*, 35, 530–536.
- Hirstein, W., Iversen, P., & Ramachandran, V.S. (2001). Autonomic responses of autistic children to people and objects. *Proceedings of the Royal Society of London, Ser. B*, 268, 1883–1888.
- Hobson, R.P. (1986). The autistic child's appraisal of expressions of emotion. *Journal of Child Psychology*, 27, 321–342.
- Humphreys, K., Minshew, N., Leonard, G.L., & Behrmann, M. (2007). A fine-grained analysis of facial expression processing in high-functioning adults with autism. *Neuropsychologia*, 45, 685–95.
- Iarocci, G., & McDonald, J. (2006). Sensory integration and the perceptual experience of persons with autism. *Journal of Autism and Developmental Disorders*, 36, 77–90.
- Kanner, L. (1943). Autistic disturbances of affective contact. *Nervous Child*, 2, 217–250.
- Lord, C., Rutter, M., Goode, S., Heemsbergen, J., Jordan, H., Mawhood, L., & Schopler, E. (1989). Autism Diagnostic Observation Schedule: A standard observation of communicative and social behavior. *Journal of Autism and Developmental Disorders*, 19, 185–212.
- Lord, C., Rutter, M., & Le Couteur, A. (1994). Autism Diagnostic Interview-Revised: A revised version of a diagnostic interview for caregivers of individuals with possible pervasive developmental disorders. *Journal of Autism and Developmental Disorders*, 24, 659–685.
- Loveland, K.A., Tunali-Kotoski, B., Chen, R., Ortegon, J., Pearson, D.A., Brelsford, K.A., & Gibbs, M.C. (1997). Emotion recognition in autism: Verbal and nonverbal information. *Developmental Psychopathology*, 9, 579–593.
- Magnée, M.J.C.M., Stekelenburg, J.J., Kemner, C., & de Gelder, B. (2007). Similar facial electromyographic responses to faces, voices, and body expressions. *Neuroreport*, 18, 369–372.
- McIntosh, D.N., Reichmann-Decker, A., Winkelman, P., & Wilbarger, J.L. (2006). When the social mirror breaks: Deficits in automatic, but not voluntary, mimicry of emotional facial expressions in autism. *Developmental Science*, 9, 295–302.
- Morris, J.S., Friston, K.J., Buchel, C., Frith, C.D., Young, A.W., Calder, A.J., & Dolan, R.J. (1998). A neuromodulatory role for the human amygdala in processing emotional facial expressions. *Brain*, 121, 47–57.
- Ozonoff, S., Pennington, B.F., & Rogers, S. (1990). Are there specific emotion perception deficits in young autistic children? *Journal of Consulting and Clinical Psychology*, 31, 343–361.
- Prior, M., Dahlstrom, B., & Squires, T.L. (1990). Autistic children's knowledge of thinking and feeling states in other people. *Journal of Child Psychology and Psychiatry*, 31, 587–601.
- Rizzolatti, G., & Arbib, M.A. (1998). Language within our grasp. *Trends in Neurosciences*, 21, 188–194.
- Rizzolatti, G., Fadiga, L., Matelli, M., Bettinardi, V., Paulesu, E., Perani, D., & Fazio, F. (1996). Localization of grasp representations in humans by PET-1:

Observation vs execution. *Experimental Brain Research*, 111, 246–252.

Rizzolatti, G., Fogassi, L., & Gallese, V. (2001). Motor and cognitive functions of the ventral premotor cortex. *Current Opinion in Neurobiology*, 12, 149–154.

Williams, J.H., Waiter, G.D., Gilchrist, A., Perrett, D.I., Murray, A.D., & Whiten, A. (2006). Neural mechan-

isms of imitation and ‘mirror neuron’ functioning in autistic spectrum disorder. *Neuropsychologia*, 44, 610–621.

Manuscript accepted 17 April 2007