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Testing the effects of expression, intensity and age on emotional face processing in ASD

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ABSTRACT

Individuals with autism spectrum disorder (ASD) commonly show global deficits in the processing of facial emotion, including impairments in emotion recognition and slowed processing of emotional faces. Growing evidence has suggested that these challenges may *increase* with age, perhaps due to minimal improvement with age in individuals with ASD. In the present study, we explored the role of age, emotion type and emotion intensity in face processing for individuals with and without ASD. Twelve- and 18–22- year-old children with and without ASD participated. No significant diagnostic group differences were observed on behavioral measures of emotion processing for younger versus older individuals with and without ASD. However, there were significant group differences in neural responses to emotional faces. Relative to TD, at 12 years of age and during adulthood, individuals with ASD showed slower N170 to emotional faces. While the TD groups' P1 latency was significantly shorter in adults when compared to 12 year olds, there was no significant age-related difference in P1 latency among individuals with ASD. Findings point to potential differences in the maturation of cortical networks that support visual processing (whether of faces or stimuli more broadly), among individuals with and without ASD between late childhood and adulthood. Finally, associations between ERP amplitudes and behavioral responses on emotion processing tasks suggest possible neural markers for emotional and behavioral deficits among individuals with ASD.

1. Introduction

Autism spectrum disorder (ASD) is characterized by deficits in social communication and reciprocal engagement, as well as the presence of repetitive behaviors and interests (American Psychiatric Association, 2013). The ability to accurately discriminate and identify emotional expressions is an essential part of every day interactions, and indeed, it seems to play an important role in social functioning for individuals with ASD (Trevisan and Birmingham, 2016). Consequently, many researchers have explored emotional face processing in ASD, measuring responses across an array of methodologies, involving both behavioral responses via established behavioral paradigms and electrophysiologically-based neural responses, such as those captured by event-related potentials (or ERP).

Behavioral assessment of emotion processing traditionally relies on paradigms asking individuals to accurately identify prototypical emotional faces. Despite the heterogeneity of results from individual studies, recent meta-analyses and reviews have generally concluded that there *is* a deficit associated with facial emotion recognition in ASD (Harms et al., 2010; Lozier et al., 2014; Uljarevic and Hamilton, 2013; but also see reviews by Jemel et al. (2006) and Nuske et al. (2013) for contrasting conclusions). However, in attempting to make sense of the wide variability of empirical evidence, many have tried to address the importance of participant characteristics – namely cognitive ability and age (e.g., Harms et al., 2010) – as well as task effects. Interestingly, two recent meta-analyses suggested that IQ does not contribute to performance in emotion recognition tasks (Lozier et al., 2014; Uljarevic and Hamilton, 2013), whereas age does: specifically, the magnitude of emotional face processing deficits *increases* with age, such that adults show more pronounced impairments than children or adolescents (Lozier et al., 2014, but see Uljarevic and Hamilton, 2013). Efforts have also been made to explore whether results might vary according to the particular emotion presented in the task; results of recent meta-analyses yield slightly different findings, but both generally suggested

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generalized impairments in emotion recognition for individuals with ASD, with the relative preservation of happy recognition (Lozier et al., 2014; Uljarevic and Hamilton, 2013).

Most of the work represented in the meta-analyses described above addressed studies that included prototypical, high-intensity facial expressions. However, in recent years, many studies have attempted to move beyond the use of prototypical exemplars of emotion to more ecologically valid emotional faces that are graded in intensity. Research with typically developing populations suggests that sensitivity to emotional expressions changes differentially with age according to the emotion being expressed. More specifically, for happy faces, children as young as 5 are as sensitive to subtle expressions as adults, but negative emotions develop along a much more protracted course, such that sensitivity to subtle expressions of anger and sadness continues to develop well into adolescence (Gao and Maurer, 2009, 2010; Herba et al., 2006; Kessels et al., 2014).

The role of emotion intensity on emotion identification for individuals with ASD has been addressed from childhood through adulthood. A study by Rump et al. (2009) is one of the few that included multiple ages; they enrolled samples of children, younger adolescents, older adolescents and adults with and without ASD. Participants were shown videos of faces progressing from neutral to emotional, with varying endpoints of intensity (25%, 50%, 75% or 100%). Although children with ASD (5–7 years of age) performed worse than their peers for fear and anger only, in the older samples, ASD was associated with worse performance across fear, anger, disgust and surprise. The authors also noted that although there was a diagnostic group difference in the adults (such that the TD sample performed better than the ASD sample), the younger age groups did not differ on overall performance. Finally, there was an important difference in the *within*-group performance: although performance in the TD group improved with age, this was not the case for the ASD sample. Similar results have been reported elsewhere (O'Connor et al., 2005).

The developmental shift noted by Rump et al. (2009) – in which relatively narrow deficits in childhood broaden to more global deficits in young adulthood – has been supported across a range of other studies. Two recent studies focused on children and young adolescents with ASD. Although TD children were more accurate in rating emotion across all intensities, groups did not differ in their recognition of anger or happiness (Evers et al., 2015; Tell, Davidson and Camras, 2014). In contrast, performance with fearful faces was less consistent in that, not surprisingly, both groups did better at higher intensities (Evers et al., 2015). Finally, performance accuracy in the ASD sample was correlated with social ability (Evers et al., 2015; Tell et al., 2014). Across both studies, then, angry and happy recognition seem to be relatively preserved for children and young adolescents with ASD, even using gradations of emotion intensity.

In slightly older samples, deficits in identifying anger begin to emerge. Two recent studies used short videos, showing expressions of increasing emotional intensity. Bal et al. (2010), in a sample of 7–17 year olds with ASD, asked participants to push a button as soon as they could recognize the emotion. Although the ASD sample showed longer reaction times, significant group differences were only observed for accuracy to anger; accuracy for other emotions did not differ by group. Law Smith et al. (2010) enrolled participants with and without ASD between 12 and 19 years of age and showed short video clips with endpoints that varied in intensity. While there was a group effect on overall accuracy, there was no main effect of intensity. Moreover, diagnostic groups *did not* differ for performance on fearful, happy or sad faces (only for disgust, anger and surprise). Of note, performance in the ASD group particularly suffered at low intensities. As in younger samples, the recognition of happy appears to be preserved, though anger and other negative emotions seem to present increasing challenges with age.

Indeed, studies focusing on older adolescents and adults have found evidence of much more global deficits, with lower accuracy across all emotions (Wingenbach et al., 2017), and particularly negative emotions such as anger, fear and sadness (Doi et al., 2013; Philip et al., 2010; Wallace et al., 2011). Moreover, adults with ASD show reduced sensitivity to intensity (Kennedy and Adolphs, 2012) and are more likely follow a particular pattern of errors: they were more likely than their TD peers to perceive negative emotions as neutral (Wingenbach et al., 2017). In sum, then, when methods include variations in intensity, individuals with ASD seem to have increasing challenges in emotion recognition with age, such that (1) deficits in recognizing happy emerge with age (there is less consistency about anger); (2) there are persistent, early-appearing difficulties with negative emotions, both perhaps due to (3) minimal improvement with age.

The bulk of the literature addressing emotional processing in ASD has involved behavioral paradigms, but there is also a smaller body of work gauging electrophysiological responses. In fact, this latter approach has been suggested to be potentially *more* sensitive to group difference than behavioral tasks (Harms et al., 2010). There are two ERP components at the center of this work: the P1 and the N170. The P1 is an early positive deflection evoked approximately 90–150 ms post-stimulus over the lateral occipital cortex that represents visual orientating and processing and is also sensitive to faces; the N170 is a negative deflection elicited over posterior visual cortical areas roughly 170 ms post-stimulus, and it has been shown to be larger in response to face vs. non-face stimuli (Bentin et al., 1996), with many researchers concluding that it is specifically sensitive to faces (Csibra et al., 2008; Eimer, 2011; Olivares et al., 2015). Both components have been shown to follow relatively predictable age-related trajectories. The P1 tends to get faster, smaller and more lateralized with age, while the N170 gets faster and follows a non-linear change in amplitude with age (it is least negative around 12 years of age, then gets more negative through adolescence) (Batty and Taylor, 2006; Kuefner et al., 2010). These two components are widely studied in the context of face processing, and, in normative populations, they have repeatedly been shown to be sensitive to facial emotion (Batty and Taylor, 2003; Meaux et al., 2014; Utama et al., 2009) and even emotional intensity (Leppänen et al., 2007; Sprengelmeyer and Jentsch, 2006; Müller-Bardorff et al., 2016; Utama et al., 2009), though it is important to note that the sensitivity of the P1 may be closely tied to low-level features of face stimuli (Rossion and Caharel, 2011).

In individuals with ASD, studies have generally measured responses to prototypical exemplars of emotion, focusing on the P1 and N170. Hileman et al. (2011) found minimal diagnostic group differences in their sample of 9–17 year olds; groups differed only in their N170 latency to emotional faces, which was relatively slower in the ASD sample than the TD sample (similar results have been reported in older samples and using neutral faces, McPartland et al., 2004; O'Connor et al., 2007). They did not find any association between these ERPs and social skills. Batty et al. (2011) when using groups matched for verbal ability, also observed minimal group differences in their sample of children with and without ASD (though differences did emerge in both the P1 and N170 when not matching for verbal ability). Both sets of authors concluded that their results did not point to marked differences in neural processing of emotional faces in individuals with ASD, at least as measured by the P1 and N170.

Some studies have combined behavioral *and* ERP measures of emotional processing. O'Connor et al. (2005) tested children (9–15 years) and adults (18-45yo) with ASD and asked them to label a set of prototypical emotional faces. In a behavioral task, the children with ASD were as proficient as their peers; however, adults with ASD were worse than TD in neutral, sad and angry (but not fear or happy). As in other studies, the control groups improved with age for sad and neutral, but there was no age-related change for the ASD group. In the ERP task (passive viewing of emotional faces), there were no diagnostic group differences in the child sample, although the adults with ASD showed a slower P1, slower N170 and smaller N170 than their TD peers. Similarly, in a sample of 6–10 year olds with ASD, Wong and colleagues

(2008) reported no group differences in amplitude or latency of the P1 or N170, nor any group difference in behavioral accuracy. Finally, one recent study – which used both ERP and behavioral paradigms – included variations in emotional intensity. Lerner et al. (2013) enrolled a sample of older children (mean age of about 13 years) with ASD and found they had an elevated error rate, relative to norms, on a standardized task of emotion processing; the authors also reported that increased error rate on the behavioral task was associated with longer N170 latencies (unlike in Hileman et al. (2011)), especially for low-intensity faces. In sum, for emotion processing, the P1 does not seem to be generally affected in individuals with ASD, although more consistent findings have emerged for the N170 (particularly for N170 latency). Moreover, N170 latency may be associated with overt behavioral measures (similar results have been reported in typically developing samples, Meaux et al., 2014), suggesting a potential underlying neural mechanism for some of the deficits noted in both lab-based and naturalistic settings.

The extant literature has established that various factors, such as emotion type, intensity, and age of participant, influence emotion processing in neural and behavioral levels. However, few studies have attempted to comprehensively address these varying factors in a single study. The present study attempts to do so in order to clarify the potential influence of each these constructs and to better understand alterations in emotion processing among individuals with ASD. Therefore, in the present study, we build upon prior work described above by combining neural and behavioral measures of emotion processing and considering the effects of emotion type and emotion intensity. Moreover, because of increasing evidence for the role of age/development, we include two samples: one group of individuals in late childhood/pre-adolescence (12-years old), and one group of young adults. These age groups were selected for two reasons: (1) in order to align the samples included in previous literature (e.g., O'Connor et al., 2005; Batty et al., 2011; Lerner et al., 2013) and (2) to capture the ages when group differences seem to become more pronounced (e.g., Rump et al., 2009). Our central questions of interest include the following:

1. What are the effects of diagnosis, age, emotion and intensity on neural processing of emotion, as captured by the P1 and N170? Both amplitude and latency will be considered.
2. What are the effects of diagnosis, age, emotion and intensity on accuracy in a behavioral (sort) task?
3. Are there associations between neural and behavioral measures of emotion processing, or with a standardized measure of ASD symptoms?

2. Methods

2.1. Participants

Consistent with prior literature in ASD (e.g., Doi et al., 2013; Evers et al., 2014; Kennedy and Adolphs, 2012; Law Smith et al., 2010; Wong et al., 2008) and because of known gender effects in emotion processing (e.g., Kessels et al., 2014; Meaux et al., 2014), we included males only in the present study. Individuals with ASD and a comparison sample of typically developing (TD) individuals were recruited, across two different age groupings: 12-year olds and 18–22-year olds. Participants were recruited through a variety of outreach approaches, including existing research databases, social media, community organizations, services providers and secondary and post-secondary schools. Exclusionary criteria included: (1) a history of neurological problems; (2) uncorrected vision problems; or (3) a diagnosis of attention deficit disorder. Members of the ASD group were required to have full-scale IQs above 70 and to meet algorithm cutoffs for ASD on the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 1999; Lord et al., 2000).

A total of 81 individuals were seen. In the 12-year old group, seven (4 TD and 3 ASD) were excluded for interference in the EEG signal and 6 members of the ASD group were excluded for not meeting criteria on the IQ/ADOS assessment (see below). In the 18–22-year olds, one participant was excluded for interference in the EEG signal (TD), one member of the TD group was excluded for self-identifying as having ASD during the visit, one was excluded for being under the influence of alcohol during the visit (TD), and three members of the ASD sample were excluded for not meeting criteria on the standardized assessment.

Table 1
Sample information.

Age group	N	Mean Age at Evaluation (in months)	SD (in months)
12-year olds			
TD	18	147.44	3.01
ASD	17	149.35	4.81
18–22-year olds			
TD	15	257.86	27.31
ASD	12	253.25	14.09

Note: Within each age group, diagnostic groups did not differ in age.

Therefore, the final sample included 62 individuals: 35 12-year old males (18 TD, 17 ASD) and 27 18–22-year old males (15 TD, 12 ASD). See Table 1 for more information. All participants in the ASD group were confirmed to have full-scale IQs above 70 and to meet criteria for Autism or ASD on the ADOS (Lord et al., 1999, 2000), administered by a research reliable examiner; see Table 2 for more information. As in the work by Wingenbach and colleagues (2016), standardized testing was not completed on the TD participants, but because this sample was predominantly recruited through local area general education classrooms and colleges, we assume their cognitive functioning to be at average levels.

2.2. Measures and procedures

Institution Review Board approval was obtained from the Boston Children's Hospital; consent was provided for by adults or, in the case of minors, by their legal caregiver. All study activities were completed in the laboratory setting.

2.3. Standardized tests

For participants with ASD, IQ and diagnostic confirmation was completed as part of the research visit. Participants received the Kaufman Brief Intelligence Test - 2nd edition (Kaufman and Kaufman, 2004), with one exception, who received the Weschler Abbreviated Scale of Intelligence (Wechsler, 1999). ASD diagnosis was confirmed using the ADOS (Lord et al., 1999, 2000), which was administered by a research reliable examiner. All 12-year olds received the ADOS Module 3, and the 18–22-year olds received the Module 4.

2.3.1. Stimuli

Stimuli were taken from the NimStim set of stimuli (Tottenham et al., 2009), two sets of RGB color photographs were used and each set featured a female adult actor. Each participant was presented with images from only one of the models for the EEG recording, and the other model for the behavioral sort task. Each set of images included a neutral face as well as emotional expressions of happiness, fear, and anger. With permission, stimuli were adopted from a previous study in which faces had been morphed to display a range of emotional intensities, ranked by percentage according to the physical displacement of facial features, from 0% (neutral) to 100% (prototypical; Gao and Maurer, 2009). In the ERP task, participants viewed each of the three emotions at intensities of 0% (neutral), 20%, 40%, and 60% (Fig. 1), for a total of 10 different expressions (the neutral expression was always

Table 2
Standardized test results for ASD sample.

	Minimum	Maximum	Mean	SD
12-year olds				
Verbal Standard Score	67	127	101.59	14.87
Nonverbal Standard Score	83	130	108.53	13.07
Total Standard Score	75	133	106.41	14.23
ADOS Communication Total	2	6	3.12	1.22
ADOS Social Total	7	10	8.41	.94
ADOS Communication + Social Total	9	15	11.53	1.59
18–22-year olds				
Verbal Standard Score	69	124	98.75	15.05
Nonverbal Standard Score	90	130	110.58	12.63
Total Standard Score	89	131	105.75	13.13
ADOS Communication Total	2	6	4.50	1.17
ADOS Social Total	6	13	8.17	2.82
ADOS Communication + Social Total	8	18	12.67	3.26

the same). For the behavioral sort task, faces were morphed in 10% increments of intensity, and ranged from 10% to 100% intensity. Each of the female models' faces was morphed for all three emotional expressions, happiness, fear and anger, for a total of 30 emotional faces, and 3 neutral faces. Photographs were printed in color on 5- by 7-in. laminated cards, and four small, labeled boxes were used to complete the sorting procedure.

2.3.2. EEG recording

While viewing the stimuli, participants wore a 128-channel HydroCel Geodesic Sensor Net (Electrical Geodesics, Inc., Eugene, OR) to facilitate electrophysiological recording. The nets connected to a NetAmps 300 amplifier located within the testing room, which referenced on-line to a single vertex electrode (Cz) and applied a .1 Hz high-pass filter to the signal. On a nearby computer, NetStation 4.3.1 (Electrical Geodesics Inc., Eugene, OR) recorded the data with a sampling rate of 250 Hz. It was recently discovered that this specific configuration for acquiring EEG can introduce a variable latency jitter into how stimuli onsets are marked in the EEG files, depending on the length of time that the impedance-check was run (Electrical Geodesics Inc., 2016). Although it is not possible to find out on an individual participant basis whether this artifact has been introduced, we conducted a set of analyses included in Supplement A that address how this potential for artifact impacts the measurement of ERP components as reported in the present studies' analyses. We found that for data collected in this lab, there were not marked or consistent effects of this acquisition configuration on any of the ERP components.

Fig. 1. Examples of stimuli depicting fearful, angry, and happy emotions at 20, 40, and 60% intensities.

2.3.3. ERP procedure

Participants were individually seated in a testing room, where they viewed the stimuli on a Tobii 120 17-in. monitor (Tobii Technology, Stockholm). The screen was positioned approximately 60 cm in front of participants, and stimuli were 15.75 cm wide by 21.5 cm high, presented against a light gray background. Black curtains surrounded the monitor and covered the walls of the testing room to minimize the presence of any distractions in the visual field. Impedances were maintained under 100 kΩ. ERPs were recorded while participants passively viewed images of human faces displaying emotional expressions of varying type and intensity. The task relied on passive (rather than active) viewing in order to isolate the neural networks integral to visual recognition of basic emotional expressions from those that may be elicited from more complex tasks that also involve attention, working memory, and/or a motor responses, for example. Scripts created in E-Prime Professional 2.0.8.22 (Psychology Software Tools, Inc., Sharpsburg, PA) initiated the series of trials, randomly selecting one of the two models to be shown in all trials. Each of the 10 expressions described above (neutral, and 20%, 40% and 60% for happy, fear and anger) was randomly presented 25 times, for a total of 250 trials. Each trial began with a fixation cross, located approximately 2 cm below the center of the screen and appearing for a randomly chosen interval between 300 and 500 ms (ms). Next, a face stimulus appeared for 500 ms, followed by a scrambled face image for 200 ms. The scrambled face acted as a mask to interrupt cognitive processing of the target stimulus, an empirical technique described in detail by Breitmeyer and Ogmen (2000). A blank screen was then displayed during a 500 ms intertrial interval. After every 62 trials, the presentation of stimuli was automatically paused to offer participants a break. The session ended when the participant had viewed all 250 trials or as otherwise necessary.

2.3.4. ERP data processing

Following data collection, each recorded file was processed using NetStation 4.5 (Electrical Geodesics Inc., Eugene, OR). A .3–30 Hz (Hz) bandpass filter was applied, and the file was segmented and corrected to include a 100 ms pre-stimulus baseline period and a 500 ms post-stimulus recording period. Using artifact detection, the file was then

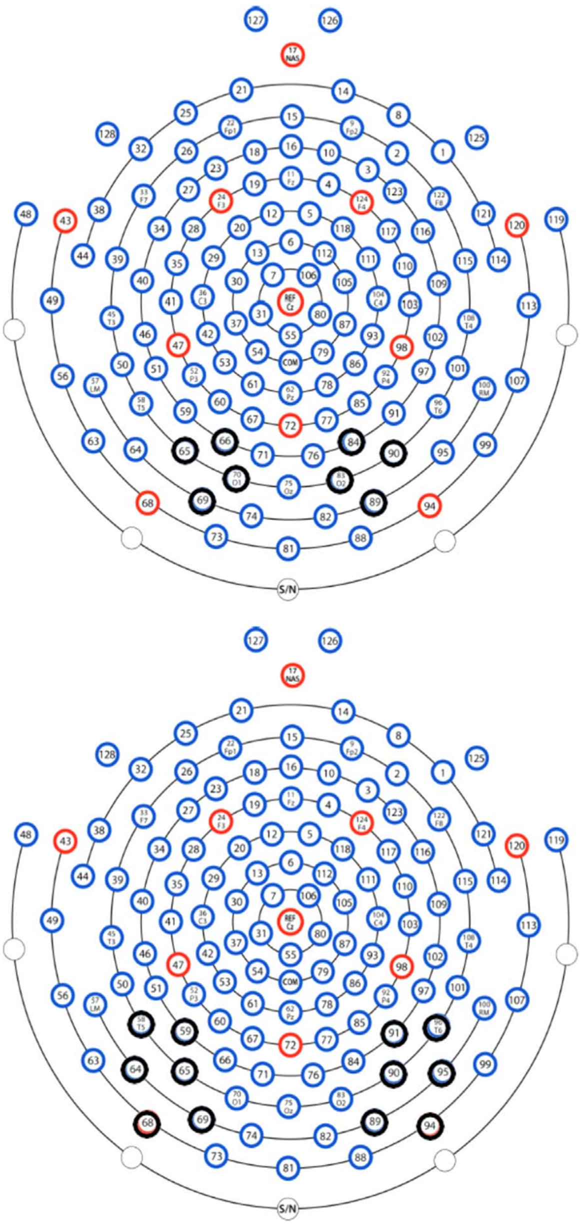

Fig. 2. Electrode groupings for P1 (top) and N170 (bottom).

screened for bad channels, eye blinks, and eye movements. Channels were considered bad if they contained high frequency noise or a voltage difference of at least 150 microvolts (μV). Any segments containing 12 or more bad channels were excluded from analysis. Subjects with fewer than 10 acceptable trials in any of the emotion categories were excluded from further analysis. If any 2 categories of emotion differed in the number of acceptable trials by 5 or more, trials with the greatest number of bad channels were removed until acceptable trial numbers were balanced across all categories. Individual means were then computed by averaging all accepted trials within each category for a single participant. During this process, the NetStation channel replacement tool was used to replace any bad channels with information interpolated from the surrounding electrodes and data were re-referenced to the average reference. All files were then baseline corrected a second time to account for recalculations that occurred during re-referencing and bad channel replacement. Averaged files were also examined to ensure that the processed data was acceptable for statistical analysis.

2.3.5. ERP data extraction

Grand means were constructed to aid in the identification of components and selection of electrode groupings (see Fig. 2 for more information). The P1 was extracted from four electrodes each over the left (65, 66, 69, 70) and right (83, 84, 89, 90) hemispheres; time windows varied slightly to accommodate age-related changes in latency. Accordingly, the P1 was extracted from 70 to 135 ms post-stimulus onset for the 12-year olds and between 65 and 120 ms post-stimulus for the 18–22-year olds. The N170 was extracted from six electrodes over the left (58, 59, 64, 65, 68, 69) and right (89, 94, 95, 90, 91, 96) hemispheres. For the 12-year olds, the N170 time window was identified from 120 to 210 ms post-stimulus onset; for the 18–22-year olds, 95–175 ms post-stimulus onset was used. Fig. 3 provides grand-averaged waveforms for each group for the P1, and Fig. 4 illustrates the N170.

2.3.6. Behavioral sort task procedure

Participants were tested in the laboratory setting, after the completion of the ERP task. At the start of the task, participants were presented with four boxes, each marked with written labels (i.e., one for 'happy', one for 'fear', one for 'angry' and one for 'neutral'). Participants were told that they would see many faces with varying emotional expressions. They were instructed to place each emotional face in the box with the matching emotional expression. Participants received one face at a time. Once they placed a face in a box, the next face was presented. Administrators responded with neutral feedback about their performance during the task. Responses were considered correct if the participant placed a face in the box with the matching emotion, and incorrect if they placed it in any other box.

3. Results

Analyses were completed addressing two sets of dependent variables: one addressing ERP response to the passive viewing task, and the second addressing behavioral responses to the sorting task.

3.1. ERP task

The four ERP dependent variables of interest included the peak amplitude of the P1, latency to the P1 peak, peak amplitude of the N170 and latency to N170 peak. A series of repeated measures ANOVAs was used, including emotion (anger, fear, happy), intensity (neutral/0%, 20%, 40% and 60%) and region (left hemisphere, right hemisphere) as within-subjects variables and group (TD, ASD) and age (12-years old, 18–22-years old) as between-subjects variables. All repeated measures ANOVA results are reported using the Greenhouse Geisser correction, and all post-hoc comparisons are reported using a Bonferroni correction.

3.1.1. P1 amplitude

A repeated measures ANOVA exploring effects on the P1 peak amplitude revealed a significant main effect of age ($F = 42.58$, $p < .001$, $\eta_p^2 = .42$). Post-hoc tests indicated a larger peak amplitude in the 12-year olds (13.77 ms) than in the 18–22-year olds (5.42 ms; $p < .001$). There was also a significant region X age interaction ($F = 5.88$, $p = .021$, $\eta_p^2 = .088$), such that the 12-year olds had a higher amplitude measured over their right hemisphere (14.89 μV) than over their left (5.31 μV, $p = .002$), but there was no region effect in the 18–22-year olds.

3.1.2. P1 latency

Results for the latency of the P1 peak indicated a main effect of age ($F = 19.19$, $p < .001$, $\eta_p^2 = .25$), such that the latency was shorter in the 18–22-year olds (90.66 ms) than in the 12-year olds (101.66 ms, $p < .001$). There was also a significant group X age interaction ($F = 4.90$, $p = .03$, $\eta_p^2 = .078$). Follow-up tests revealed that although

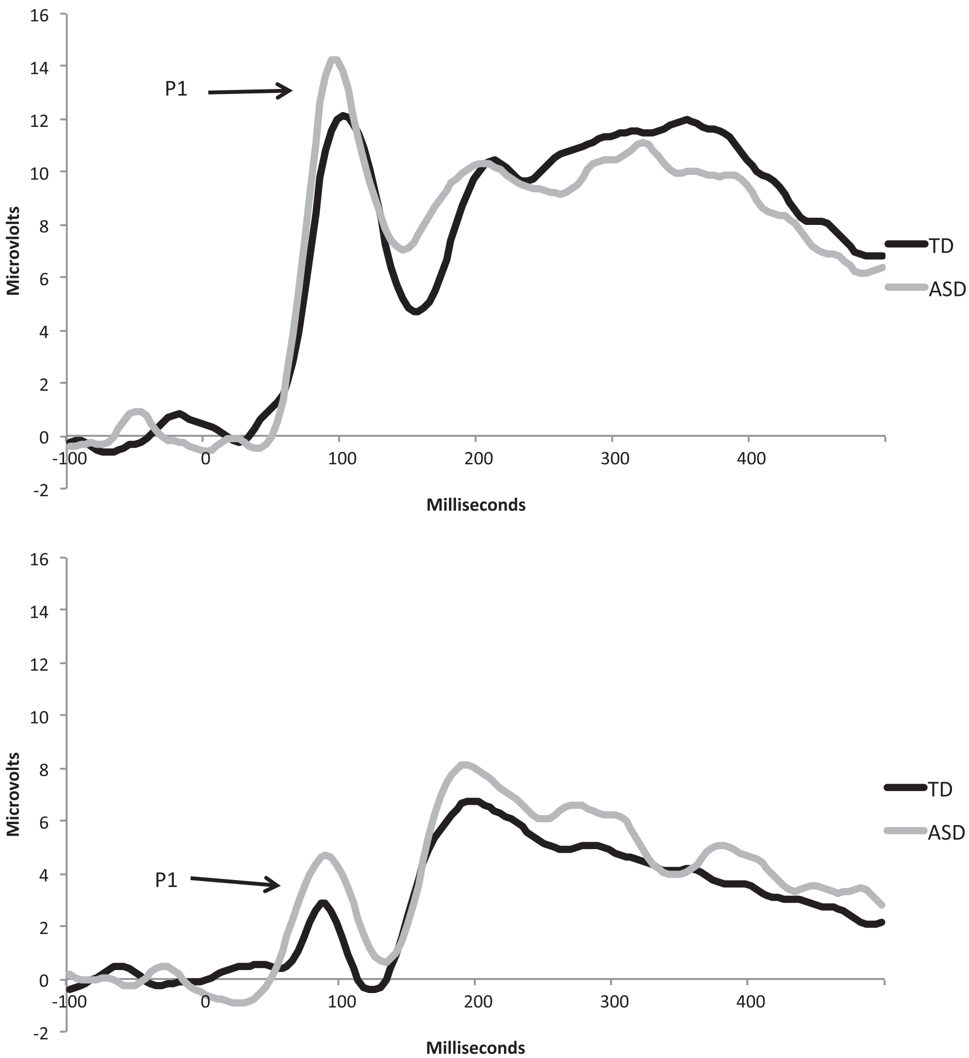

Fig. 3. P1 grand averaged waveforms for neutral faces for 12-years olds (top) and 18–22-year olds (bottom). Figures show averaged data from the right hemisphere region of interest. Waveforms have a 100 ms pre-stimulus and 500 ms post-stimulus interval.

the latency did not differ between groups at 12-years of age, there was a significant group difference in the 18–22-year olds: the TD group showed a shorter latency (86.22 ms) than the ASD group (95.10 ms, $p = .02$). Similarly, although the TD latency shortened with age, decreasing from 102.78 ms at 12-years to 86.22 ms in young adulthood ($p < .001$), there was no significant age-related change in the ASD group (12-years: 100.53 ms; 18–22-years: 95.10 ms, $p = .145$).

3.1.3. N170 amplitude

Results from the repeated measures ANOVA for N170 peak amplitude indicated a main effect of age ($F = 4.40$, $p = .04$, $\eta_p^2 = .071$), such that the amplitude was more negative in the 18–22-year olds (−2.27 µV) than in the 12-year olds (−.44 µV, $p = .04$). No other main effects or interactions were significant.

3.1.4. N170 latency

The N170 latency to peak showed main effects of age ($F = 78.75$, $p < .001$, $\eta_p^2 = .576$), emotion type ($F = 7.48$, $p = .001$, $\eta_p^2 = .114$), intensity ($F = 5.11$, $p = .005$, $\eta_p^2 = .081$) and group ($F = 8.63$, $p = .005$, $\eta_p^2 = .13$). Follow-up tests were completed to explore each main effect. With regards to age, the N170 latency was shorter in the 18–22-year olds (129.96 ms) than in the 12-year olds (160.34 ms, $p < .001$). For emotion type, the latency to happy faces was shorter (143.83 ms) than to angry (145.99 ms, $p = .003$) or fearful faces (145.63 ms, $p = .014$). The effect of intensity was strongest in the contrast between latencies to 20% faces (143.78 ms) and 60% faces (146.91 ms, $p < .001$); no other contrasts were significant. Finally, the TD group showed a shorter mean latency (140.12 ms) than the ASD group (150.18 ms, $p = .005$).

There was also a significant emotion X age interaction ($F = 4.04$, $p = .021$, $\eta_p^2 = .065$). Follow-up tests indicated that for 12-year olds (but not for young adults), the latency to angry faces (162.15 ms) was significantly longer than to happy faces (158.51 ms, $p < .001$).

3.2. Behavioral sort task

3.2.1. Overall task accuracy

We first examined whether groups (TD, ASD) differed in their accuracy rates (i.e. their overall likelihood of correctly classifying a face) overall, and whether this overall group difference varied across age groups (12-year olds, 18–22-year olds). We used a GEE (Generalized Estimating Equation) model, with intensity as the within subjects factor and Group (TD, ASD) and Age (12-year olds, 18–22-year olds) entered as a between subjects factors and we stratified our analyses by emotion. There was no significant main effect or interaction of Group or Age for the happy condition or the angry condition. However, for fearful faces, there was a main effect of age on accuracy rates; 12-year olds (M = .68, 95% CI: .63–.72) showed significantly lower accuracy rates when compared to young adults (M = .76, 95% CI: .73–.79).

3.2.2. Specific emotion msidentifications

The previous model examined overall accuracy rates, defined in terms of whether or not an emotional face was accurately identified.

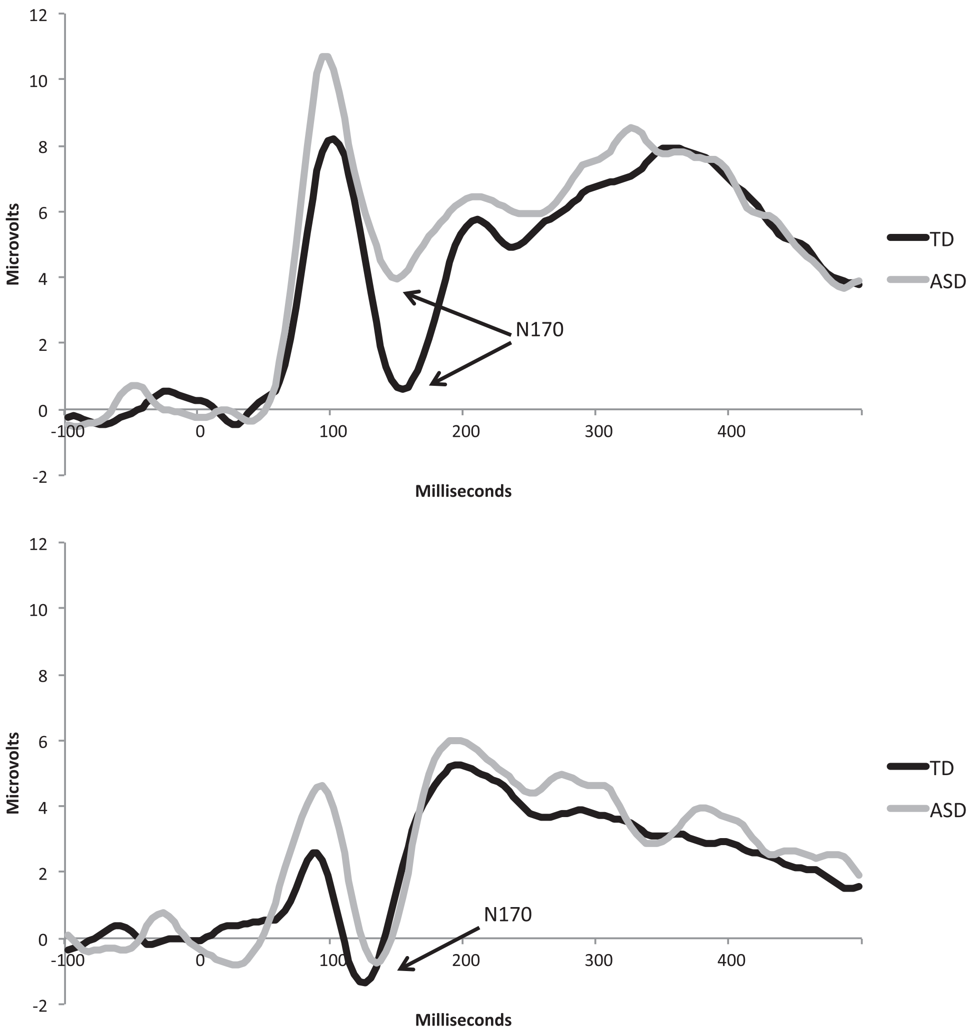

Fig. 4. N170 grand averaged waveforms for neutral faces for 12-year olds (top) and 18–22-year olds (bottom). Figures show averaged data from the right hemisphere region of interest. Waveforms have a 100 ms pre-stimulus and 500 ms post-stimulus interval.

However, inaccuracy could be due to either identification of the emotional face as neutral *or* identification of the emotional face with an incorrect emotion. In an effort to separate these two error types, in the next steps in our analyses, we did not count neutral responses as incorrect, given that all faces, with the exception of the extreme versions, contained some neutral emotion. Therefore, incorrect responses were now only calculated for cases in which one emotion was misidentified as another. A GEE was used to examine misidentification rates with group (TD, ASD) and age (12 year, Adult) as between subjects factor. We ran separate models for each emotion condition. No significant main effects or interactions between Group and Age emerged for misidentification rates for happy, fearful, or angry faces.

3.2.3. *Emotion thresholds*

We also calculated threshold values for each condition, defined as the point at which participants are equally likely to classify a face as emotional or not (the 50% point), consistent with prior work (Gao and Maurer, 2009). Using the NLS package in R (version 3.30, © 2016), we calculated threshold values for each group and emotion condition. For each threshold value, we calculated Wald-type 95% CIs for each group and emotion. Non-overlapping 95% CIs indicate significant group differences. Variability in threshold values indicated variability in the perceptual boundary, or intensity value at which faces begin to be correctly identified. We stratified our analyses by emotion and age. Threshold values, or intensity values at which emotional faces were correctly identified, did not vary as a function of ASD or TD group membership for any emotion. Threshold values did not significantly differ for 12 years olds across any emotion group. Adults' thresholds did not significantly differ for fear and anger. However, adults showed significantly lower threshold values for correctly identifying happy faces when compared with fear and anger.

3.3. *Cross-task associations*

In order to explore associations across the ERP amplitude/latency and behavioral tasks, as well as associations of performance in both tasks with ASD symptoms, several new variables were extrapolated from the data described above. The within-subjects design of this study yielded a high number of ERP variables available for correlational analyses. To reduce the number of correlations that were calculated, we averaged across region and emotion (in keeping with prior literature; Hileman et al., 2011; Meaux et al., 2014). However, due to previous evidence that individuals with ASD may experience particular difficulty with facial emotion processing at low or moderate intensities (Doi et al., 2013; Law Smith et al., 2010), this within-subject condition was maintained. Data from the behavioral sort task was reduced into two new variables; the first variable captured total number of incorrect responses on the sort task and the second captured the number of correct responses in emotion identification, across happy, fearful and angry faces. Note that because identifying a face as "neutral" was neither considered correct or incorrect, these two variables retain some independence. Two participants were missing data for these variables because of partial missing data in the sort task. Finally, ASD symptoms were captured using the ADOS Communication and Social Total algorithm scores. Higher algorithm scores indicate higher ASD symptoms. [Note: Because the ADOS (Lord et al., 1999, 2000), not the ADOS-2 (Lord et al., 2012), was used, Standardized Comparison Scores are not available for this sample.] Because of the number of comparisons made, a significance threshold of $p < .01$ was used throughout.

First, correlations were calculated to address associations between response in the ERP task and performance in the sort task. Correlations were run separately by diagnostic group and age group, and due to small cell sizes, Spearman correlations were used. There were no significant correlations for the TD group, in the 12-year olds or the 18–22-year olds, nor were any correlations significant in the 12-year olds with ASD. For the 18–22-year olds with ASD, a significant negative correlation between number of errors made and P1 amplitude to 40% intensity was observed, $\rho = -.82$, $p = .004$, indicating that smaller amplitudes to 40% intensity faces were associated with more sort task errors.

Next, Spearman correlations were calculated to explore associations between ERP response and ADOS communication and social algorithm total (for ASD sample only, split by age). For the 12-year olds, P1 amplitude to 20% faces was negatively correlated with algorithm scores, $\rho = -.64$, $p = .006$, such that smaller P1 amplitudes were associated with higher algorithm totals. There were no significant correlations between ERP and ADOS scores for the 18–22-year olds. Finally, Spearman correlations between ADOS communication and social algorithm total and sort task performance were calculated (for ASD sample only, split by age). Results were not significant.

4. Discussion

We explored the role of ASD diagnosis, emotion type, emotion intensity and age in emotional face processing, as measured through ERP and a behavioral task. This is the first study, to our knowledge, to simultaneously take into account these multiple factors in order to more carefully consider potential maturational differences among individuals with ASD. Diagnostic group (i.e., TD vs. ASD) findings will be discussed first, followed by a brief discussion of our other findings.

Within the ERP metrics, we observed an interaction between group and age for the P1 latency, such that although it decreased between 12-years old and 18–22-years old in the TD group, no such difference was observed in the ASD group. This apparent plateauing in P1 speed is similar to previous findings in ASD samples that suggest reduced developmental change in other metrics of face processing (O'Connor et al., 2005; Rump et al., 2009), and that the magnitude of deficits may increase with age (Lozier et al., 2014). It has widely been noted that individuals with ASD show slowed latencies across a number of ERP components (e.g., Jeste and Nelson, 2009; Orekhova and Stroganova, 2014), and our results suggest that there may be a complex interplay between globally slowed processing speed, reduced developmental changes in neural function, and the relative worsening of higher order deficits. Hileman et al. (2011) noted that developmental effects may dwarf the effects of diagnostic group in emotional face processing; our results confirm this but also suggest that there may be important interactions between these two factors.

We also found that the latency of the N170 varied by diagnosis: across both age groups, the ASD sample evinced a slower N170 than the TD group. This is also consistent with a number of previous studies, which have used both neutral and affective faces (Hileman et al., 2011; McPartland et al., 2004; O'Connor et al., 2007). Across the ERP findings, the measures of latency – to P1 and N170 – were more sensitive to group, suggesting that the group differences in the speed of processing may be most informative in understanding the nature of ASD-related deficits. Interestingly, the main effects of emotion and intensity on N170 latency indicate that the N170 for *both* diagnostic groups was affected by emotion type and intensity. Moreover, we did not find any evidence that latency is differentially affected by different emotional expressions or intensities. Overall, these results suggest that individuals with ASD are indeed sensitive to emotion type and intensity (as are their typically developing peers), and that there may be more global differences in processing speed rather than deficits pertaining to specific emotion-related tasks. However, we can not speak directly to the specificity of these latency differences to face vs. non-face stimuli because the latter were not included in this study; future work should continue to disentangle the role of generalized differences in the speed of visual processing and specific deficits in processing emotional faces.

The lack of group differences in the behavioral task is somewhat surprising, but given the inconsistency of findings in the literature, there is certainly a precedent for null findings in emotion recognition tasks, particularly for younger samples (Evers et al., 2014; Fink et al., 2014; Harms et al., 2010; Jones et al., 2011; Lozier et al., 2014). At the very least, these findings are in line with previous claims that emotion recognition is either extremely variable in ASD or not an area of marked impairment, or both (Batty et al., 2011; Hileman et al., 2011; Jemel et al., 2006; Nuske et al., 2013).

Finally, we explored potential associations across tasks and found that the amplitude of the P1 – especially to low and moderate intensity expressions – was negatively correlated with sort task errors and ADOS algorithm scores: smaller amplitudes was associated with more errors and higher levels of ASD symptoms. Other studies have reported associations between the N170 latency – also to low-intensity faces – and sort task errors in individuals with ASD (Lerner et al., 2013), while others have found no association at all (Hileman et al., 2011). We are not aware of any prior work suggesting associations between ERP amplitude and overt emotion-processing or social behaviors for individuals with ASD. Given that *latency* seems to be more globally sensitive to diagnostic group differences, we will be curious to see if this finding is replicated in future work. In contrast to previous work (Evers et al., 2015; Tell et al., 2014), we did not find any associations between sort task metrics and ADOS scores. This could perhaps due to the measurement approach; the present study used the ADOS algorithm total to capture ASD behaviors, while previous work has relied on the Social Responsiveness Scale (or SRS, Constantino and Gruber, 2007), which may be more suitable to capture individual variability in ASD symptoms.

A number of our findings aligned with prior literature in typically developing populations on the effects of age and emotion on the P1 and N170. The P1 showed pervasive age-related effects, such that the P1 decreased in amplitude and latency with age; these findings are consistent with previous findings (e.g., Batty and Taylor, 2006; Kuefner et al., 2010; Hileman et al., 2011). However, we found no effects of emotion or intensity on the P1 amplitude or latency. There is prior evidence of the P1's sensitivity to these two factors (Batty et al., 2011; Meaux et al., 2014), but other studies have failed to find evidence for it (Batty et al., 2011; Wong et al., 2008; O'Connor et al., 2005). As with the P1, the N170 showed expected age-related changes, getting faster and increasingly negative with age (e.g., Batty and Taylor, 2006; Batty et al., 2011; Hileman et al., 2011; Kuefner et al., 2010; Taylor et al., 2004). The latency of the N170 showed main effects of emotion and intensity, as in previous work (Meaux et al., 2014; Sprengelmeyer and Jentzsch, 2006; Utama et al., 2009).

Our behavioral task suggested that although accuracy for happy and angry faces did not increase with age, accuracy for fear faces did. These findings are consistent with previous reports of the early mastery of happy and the protracted development for fearful faces (Gao and Maurer, 2009, 2010). The literature is more mixed for angry faces (Gao and Maurer, 2009, 2010; Herba et al., 2006; Kessels et al., 2014). We did not find any particular patterns in misidentification – or any differences by group – but we did observe that adults had a lower intensity threshold for happy faces than for angry/fearful faces. This is somewhat unexpected, as it is inconsistent with prior literature using very similar materials (e.g., Gao and Maurer, 2010).

There are important limitations to this work that should be noted. First, our sample of 12-year-old youth was more constricted in age range than our sample of young adults. Moreover, our sample included only males and the ASD sample was limited to individuals with full-scale IQs above 70; both of these factors exclude important segments of the ASD population and reduce the generalizability of findings. Finally, we did not evaluate cognitive functioning in the TD sample to confirm whether it was comparable to that observed in the ASD sample. Prior research has pointed to potential associations between IQ and ERP metrics (particularly latency; e.g., Jaušovec and Jaušovec, 2000; Hansell et al., 2005), with higher cognitive functioning predicting faster latencies. We are unable to evaluate whether and to what extent the observed latency differences reported here are associated with individual and/or group differences in IQ, but future work should more thoroughly explore the role of cognitive functioning as an additional variable of interest.

Other limitations in study design should be noted. Both of our tasks used static expressions of emotion; though these were optimal for use in an ERP study, they lacked real-world validity. Further, only face stimuli were used in our behavioral and ERP tasks. Future work may consider including additional non-face and non-social stimuli as controls. Moreover, the ERP task relied on images from only one actor, which might have affected visual adaptation and potentially limit generalization. In terms of component selection, we focused exclusively on the P1 and N170; the inclusion of other, later components focusing on higher-order emotion processing might have yielded different results. Finally, incorporating additional assessments of social behavior, beyond that provided by the ADOS algorithm, may help to capture more fine-grained differences in social abilities.

Overall, our results provide further evidence for important differences in face processing for individuals with ASD. We observed group differences in N170 latency, as well as reduced age-related change in the P1 latency, both of which extend prior work. However, those group differences in ERP seemed to capture speed of processing in broad strokes, rather than difficulty with *specific* expressions or clarity of emotion. This is consistent with the observations of Lerner et al. (2013), who point to the importance of “social information processing speed” as an important construct underlying observed deficits in social emotional function. Future work might benefit from focusing on the role of processing speed, and taking an individual differences approach, to make sense of the heterogeneous pattern of findings in this field.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.neuropsychologia.2017.06.023.

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