Published in final edited form as:

J Autism Dev Disord. 2014 June ; 44(6): 1332–1346. doi:10.1007/s10803-013-1993-6.

Using the Circumplex Model of Affect to Study Valence and Arousal Ratings of Emotional Faces by Children and Adults with Autism Spectrum Disorders

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Electronic supplementary material The online version of this article (doi:10.1007/s10803-013-1993-6) contains supplementary material, which is available to authorized users.

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Abstract

The Affective Circumplex Model holds that emotions can be described as linear combinations of two underlying, independent neurophysiological systems (arousal, valence). Given research suggesting individuals with autism spectrum disorders (ASD) have difficulty processing emotions, we used the circumplex model to compare how individuals with ASD and typically-developing (TD) individuals respond to facial emotions. Participants (51 ASD, 80 TD) rated facial expressions along arousal and valence dimensions; we fitted closed, smooth, 2-dimensional curves to their ratings to examine overall circumplex contours. We modeled individual and group influences on parameters describing curve contours to identify differences in dimensional effects across groups. Significant main effects of diagnosis indicated the ASD-group's ratings were constricted for the entire circumplex, suggesting range constriction across all emotions. Findings did not change when covarying for overall intelligence.

Keywords

Circumplex model of affect; Valence; Arousal; Autism spectrum disorders; Facial emotion

Introduction

Few visual stimuli are as socially salient as the faces of our fellow humans. Faces not only convey critically important social cues, such as age, sex, emotion, and identity, but they are also the primary vehicle for both verbal and non-verbal communication (Batty and Taylor 2006). In effect, the accurate interpretation of facial emotions is an important predictor of the success of a person's social interactions.

Autism Spectrum Disorders (ASD) are a set of complex neurodevelopmental disabilities defined by the presence of qualitative impairments in reciprocal social interaction, impairments in early language and communication, and restrictive, repetitive and stereotyped behaviors (American Psychiatric Association 2000). Early signs of ASD include reduced attention to faces and reduced eye contact with others (Hobson 1993; Osterling et al. 2002; Phillips et al. 1992). Often individuals with ASD have trouble recognizing facial expressions, which may impair their ability to understand the intentionality and minds of others, an important component of social communication (Golan et al. 2006; Grelotti et al. 2002; Hobson 1993; Klin et al. 2002).

Although a disorder of socialization such as ASD is commonly thought to include impaired emotional functioning (i.e., emotion recognition, autonomic responsiveness), evidence in support of this claim from prior studies is inconsistent. Whereas several studies have reported significantly poorer emotion recognition in adults and children with ASD compared

to typically developing (TD) individuals (Ashwin et al. 2006; Tantam et al. 1989) and persons with other neurodevelopmental disorders (Celani et al. 1999; Riby et al. 2008), several studies have also reported normal emotion recognition in children with ASD (Castelli 2005; Ozonoff et al. 1990). Whether individuals with ASD who are impaired in recognizing emotions have this difficulty for all emotions, or only for a particular set of emotions, is unclear. Significant disparities between ASD and TD groups on emotion recognition or understanding, for example, have been reported for Fear alone (Pelphrey et al. 2002); Sadness alone (Wallace et al. 2011); for Anger and Happiness (Wright et al. 2008); for Fear, Anger, and Disgust (Ashwin et al. 2007); and for Fear, Disgust, and Happiness (Humphreys et al. 2007).

Researchers have also been unable to reach consensus on the role of autonomic arousal in the impaired emotional functioning of individuals with ASD. Several studies have reported near-normal autonomic responses during emotion induction paradigms when measuring physiological responses in participants with ASD. For example, one study showed that high-functioning children with ASD and typically-developing children exposed to pleasant, unpleasant, and neutral pictures did not differ in skin conductance responses (Ben-Shalom et al. 2006). Findings were similar for low-functioning children with ASD and TD children exposed to neutral pictures and distress cues. However, the same participants with autism were hyporesponsive to threatening stimuli (Blair 1999). Children with ASD and TD children also exhibited similar facial expressions and autonomic responses to pleasant and unpleasant odors. Despite these similarities across diagnostic groups, children with ASD were less likely to report an emotional reaction to the odors that matched their facial response, indicating problems when self-reporting of emotional states (Legiša et al. 2013). Moreover, several studies of children with ASD have drawn correlations between autonomic findings and psychosocial behavior. For example, several studies have reported that persons with ASD have difficulties in the processing and labeling of their own emotions, including problems integrating bodily sensations of emotional arousal, recalling previous emotions, and identifying and describing feelings (Capps et al. 1992; Hill et al. 2004; Losh and Capps 2006; Rieffe et al. 2007). Additionally, studies of heart rate variability, pupil size, salivary alpha-amylase, and electrodermal responses have also shown that children with ASD differ from typically developing children in their autonomic responsiveness to viewing human faces as well as when performing other mental tasks (Bal et al. 2010; Kaartinen et al. 2012; Lioy et al. 2011; Martineau et al. 2011; Ming et al. 2011).

Recently, the polyvagal theory (Porges et al. 1996) has been used to inform studies of autonomic arousal and its relation to social behavior in individuals with autism. In mammals, the myelinated vagus serves as a well-regulated “vagal brake” in safe social situations to alter visceral state quickly by either speeding up or slowing down heart rate. The vagal brake decreases heart rate, thus promoting calm behavioral states that may foster social interaction. Cardiovagal tone, or the dynamic influence of the myelinated vagus nerve, can be assessed by quantifying the amplitude of respiratory sinus arrhythmia (RSA) (Porges 2007). The polyvagal theory suggests that in persons with poor vagal regulation, sympathetic influences to the heart will be unchecked, and these individuals will be unable to curb the naturally occurring sympathetic reactivity to emotional stresses (Beauchaine et al. 2011). A number of studies appear to support the theory of a hypersympathetic state in

autism that is insufficiently attenuated by vagal parasympathetic influences. Children with ASD, for instance, have been shown to have significantly lower amplitude RSA and faster heart rate than TD children at baseline, prior to an emotional stress, suggesting the presence of a lower overall vagal regulation of heart rate (Bal et al. 2010; Ming et al. 2005; Vaughan Van Hecke et al. 2009). Also, children with ASD who have higher baseline RSA amplitudes showed greater RSA reactivity during attention-demanding tasks, and they demonstrated better social behavior (Patriquin et al. 2013). These findings suggest that individuals with ASD may be in a hypersympathetic state with diminished capacity for calm behavior, which may in turn contribute to their impaired responses to anxiety-provoking situations and their difficulties with social interactions.

Various explanations may account for the widely disparate findings in research examining emotional face processing in individuals with ASD. For example, differences in demographic characteristics (e.g., age, IQ) of the participant groups, task demands, and measurement outcome across studies almost certainly contribute to inconsistencies in findings. Studies that show no group differences between ASD and TD groups may be confounded by any number of features of the ASD group that are not found in the TD group (e.g., lower mental age, the presence of comorbidities, and discrepancies in verbal and performance IQ) (Burack et al. 2004). Another source of inconsistency in findings across studies is the variability in experimental paradigms used to assess processing of facial emotions, such as the nature of the face stimuli (e.g., static, morphing or blended, dynamic), the dependent variables measured (e.g., recognition accuracy, reaction time), and task demands (e.g., level of difficulty), which have varied greatly across studies (see Harms et al. 2010 for review). While all of these are important and legitimate possible confounds, we propose that another explanation may account for many of the inconsistencies in findings across studies.

Discrepancies in findings from previous research studies of recognizing and understanding emotions in individuals with ASD may be attributable, in part, to inherent limitations and inconsistencies in the underlying model of emotion assumed when designing those studies, which has generally been the traditional Theory of Basic Emotions or discrete emotion theory. This theory posits that a core set of distinct emotions (e.g., Anger, Sadness, or Happiness) each derives from a distinct neural system that manifests in discrete patterns of autonomic response, motor behavior, and facial expressions (Ekman 1992; Panksepp 1992). Previous reviews have presented the many limitations and inconsistencies of this theory, including the absence of one-to-one mappings of individual emotions to specific facial expressions, motor behaviors, and autonomic responses, and the absence of evidence for a core set of emotions from which other emotions derive (Ekman 1993; Posner et al. 2005; Russell 1980). Additionally, compared with findings from animal studies, direct evidence supporting the theory of basic emotions in humans is limited (Berridge 2003). Many functional imaging studies, for example, have examined neural activity in response to individual emotions when contrasted with activity in response to stimuli intended to be emotion-neutral. Findings across these studies of discrete emotions have been notoriously inconsistent and have failed to generate a comprehensive understanding of the neural systems that subserve emotional experience (Barrett and Wager 2006; Berridge 2003; Cacioppo et al. 2000; Davidson 2003; Ortony and Turner 1990). If the one-emotion/one-

circuit idea is incorrect, then discrete emotion theory could not lead to a better understanding of the neurophysiological abnormalities underlying ASD. Also, because the majority of investigations informed by the basic theory have only included a few emotions, and those tended to be either high arousal/negative valence stimuli (i.e., Fearful, Angry), low arousal/negative valence stimuli (i.e., Sad), or moderate arousal/positive valence stimuli (i.e., Happy), researchers have had difficulty disentangling measures of arousal and valence. For example, as happy is generally the only positive valence emotion studied, comparisons to negative valence or neutral stimuli may be confounded by the fact that happy is a positive arousal emotion. Essentially, reported differences between happy and other emotions that are attributed to differences in valence may be due, in part, to differences or similarities in arousal.

An alternative theoretical framework is the “Circumplex Model of Affect,” which holds that all emotions derive from two underlying, orthogonal dimensions of emotional experience, valence and arousal (Colibazzi et al. 2010; Gerber et al. 2008; Posner et al. 2005, 2009). This model of emotion has been replicated through multiple lines of inquiry including factor analytic and scaling procedures of emotional terms and facial expressions (Kring et al. 2003; Russell 1980; Schlosberg 1952). Studies investigating subjects’ self-reports of affective experience have yielded similar results (Feldman-Barrett and Russell 1998; Watson and Tellegen 1985). In this circumplex model, the valence dimension describes hedonic tone, or the degree to which an emotion is pleasant or unpleasant, and the arousal dimension describes the degree to which an emotion is associated with high or low energy (Fig. 1).

The model proposes that all emotions can be represented as a linear combination of the dimensions of arousal and valence with all emotions shading imperceptibly from one into another along the contour of the two-dimensional circumplex (Posner et al. 2005). Under this rubric, “happiness” is the product of strong activation in the neural system associated with positive valence and moderate activation in the neural system associated with positive arousal. Other emotional states arise from the same two underlying neurophysiological systems but differ in degree of activation of each. The circumplex model furthermore suggests that the labeling of our subjective experience as one emotion rather than another nearby emotion is the consequence, in part, of *cognitive interpretation* of the neurophysiological experiences of arousal and valence within the situational context (Russell 2005). A small number of studies have shown that these ratings of arousal and valence do correlate with various neurophysiological indices in typically-developing adults (Colibazzi et al. 2010; Gerber et al. 2008; Posner et al. 2009).

We asked ASD and TD participants to rate the feelings depicted in a broad range of facial emotions by thinking about how the person in the picture feels. We then characterized quantitatively the contours of their affective circumplexes to assess and compare collectively the spectrum of emotions reported by the participants. To our knowledge, no prior studies have used subjective ratings of arousal and valence to examine emotional response to facial expressions in children and adults with ASD, particularly for such a wide span of emotions. Although clinical lore has long supported the idea that individuals with ASD may experience a more restricted range of emotions, only a small number of studies have actually provided empirical evidence to support the notion. However, based on these few prior

behavioral and electrophysiological studies (e.g., Ben-Shalom et al. 2006; Hubert et al. 2009), we hypothesized that emotional recognition and understanding, as represented by the numerical parameters for valence and arousal that determine the overall contour of the affective circumplex, would be narrower in range for ASD compared to TD participants. This behavioral study will provide unique insight into the emotional experience of individuals with ASD, and it will have important implications for elucidating the neurophysiological underpinnings of arousal and valence in persons with ASD.

Methods

Study procedures were approved by the Institutional Review Board.

Participants

We recruited 51 individuals with ASD (6F, Ages: 7–60 years, Mean: 26.5 ± 13.8 years) and 80 TD individuals (21F, Ages: 7–61 years, Mean: 24.1 ± 11.8 years) from a metropolitan area. A wide age-range was included in order to understand better the developmental trajectory of emotional processing in this under-studied group. For example, if the child participants with ASD performed similarly to our adult participants with ASD, then we might infer that any emotional deficits found are likely a static, trait-like disturbance. We also hoped to use cross-sectional data from this investigation to generate hypotheses for future longitudinal research. Groups were matched by age, sex, IQ (Wechsler Abbreviated Scale of Intelligence, WASI (Wechsler 1999)), handedness (Edinburgh Handedness Inventory (Oldfield 1971)), race, and socioeconomic status (Hollingshead Index of Social Status, SES (Hollingshead 1975)). Mean full scale IQ (FSIQ) was 110.9 ± 24.6 for the ASD group and 116.1 ± 12.7 for the TD group (Table 1).

Participants with ASD were recruited from a Developmental Neuropsychiatry Clinic at a large university medical center and community outreach initiatives. Participants with ASD were evaluated by an expert clinician and met Diagnostic and Statistical Manual of Mental Disorders, Fourth Edition, Text Revision (DSM-IV-TR) (American Psychiatric Association 2000) criteria for autistic disorder, Asperger's syndrome, or pervasive developmental disorder-not otherwise specified (PDD-NOS) (Table 1). Diagnoses were also confirmed with the Autism Diagnostic Interview Revised (Lord et al. 1994) and the Autism Diagnostic Observation Schedule (ADOS) (Lord et al. 1989). As an additional measure of social behaviors and severity of symptoms, parents of children with ASD were also asked to complete the Social Responsiveness Scale (SRS), a measure of social/emotional behavior, including social awareness, social information processing, reciprocal behavior, social anxiety and avoidance, and characteristics of autistic traits (Constantino and Gruber 2005). The SRS has five subscales (i.e., Social Awareness, Social Cognition, Social Communication, Social Motivation, and Autistic Mannerisms) and generates a single scale score, which serves as an index of severity of social deficits in ASD. TD controls, recruited through advertisements and from community-based telemarketing lists, were excluded if they met DSM-IV-TR criteria for current Axis-I-disorder or if they had any indication of developmental delay and other indicators of ASD, lifetime history of psychotic or substance

abuse disorder, or if they had history of head trauma, seizure disorder, or other neurological disorder. None were taking psychotropic medications.

Affective Circumplex Task

Participants were shown emotional faces on a screen during functional magnetic resonance imaging (fMRI) scanning and asked to rate the arousal and valence of faces simultaneously by clicking a computer mouse to select a box on a 9×9 2-dimensional grid (Fig. S1). To simplify description, the facial stimuli presented were assigned labels (Angry, Bored, Contented, Disgusted, Fearful, Happy, Neutral, Sad, Scared, Sleepy, Surprised) based on how these facial stimuli have been generally classified by typically developing adults (e.g., Russell and Bullock 1985). However, these labels were not shared with the participants. Each participant was told, “You will be shown a face that expresses a certain feeling. You will be asked to assess the feeling on the chart shown below... On the chart, the vertical dimension represents degree of arousal. Arousal has to do with how awake, alert, or energetic a person is... The right half of the chart represents pleasant feelings—the farther to the right, the more pleasant. The left half represents unpleasant feelings—the farther to the left, the more unpleasant... During the experiment, you will first be shown a face. This will appear on the screen for 15 s. Then you will be shown the grid. When the grid appears, you will click on the area you think best describes the face... Try to think about the feeling expressed by the face during the 15 s that it is shown. It will not be on the screen when you are shown the grid.”

At the time of instruction and during the experiment itself, the words “High Pleasure” appeared to the right of the grid, and “High Energy” above the grid. The location of the box along the X-axis indicated the participant’s rating of valence (left = negative valence, right = positive valence), and the location along the Y-axis indicated the rating of arousal (top = high arousal, bottom = low arousal). Prior behavioral studies have shown that the 9×9 affective grid provides ratings of valence and arousal similar to those obtained when these two affective dimensions are rated separately (Russell et al. 1989). We recorded the selected box as two integer scores, each ranging from -4 to $+4$, encoding the valence and arousal of the participant for that face.

Each trial consisted of 3 components presented in succession: (1) Visual presentation for 18 s one of the 20 distinct human faces used in the studies of the affective circumplex (Russell and Bullock 1985). Thirteen of these 20 faces were taken from Pictures of Facial Affect (Ekman and Friesen 1976) and depicted expressions of a number of emotions (two faces of each emotion, classified as expressing happiness, surprise, fear, anger, disgust, or sadness, and one commonly classified as neutral). This set was supplemented with additional stimuli to better represent the portions of the circumplex under-sampled by the Ekman series (i.e., emotions associated with low arousal but positive or neutral valence) (Russell and Bullock 1985). These include two photographs each of actors and actresses expressing boredom, contentment, or sleepiness, as well as one expressing excitement. (2) Visual presentation of a 2-D grid on which participants indicated their ratings of arousal and valence for each face by moving an arrow controlled by a computer mouse. This screen remained visible until the participant clicked the mouse button, up to a maximum of 20 s. (3) Visual presentation of a

fixation point (+) at the center of the participant's visual field. The fixation point was displayed immediately following the rating of valence and arousal. The durations of rating and gaze fixation were each variable, but when summed together always equaled 20 s. Each run consisted of 20 trials presented in a pseudorandom order (but uniform from subject to subject), and we acquired three runs (totaling 60 stimulus trials) for each person (See Fig. 2). Although the facial emotion task was conducted as part of an fMRI study, only task data are presented here in order to focus on the behavioral differences between groups.

Prior to the study session, all participants were given a practice session with the task so that they could familiarize themselves with task instructions, the types of stimuli they would be seeing (practice stimuli were not shown during the study session), the grid on which they would be rating arousal and valence, and the computer mouse they would be clicking to indicate their ratings. Researchers were available to review the practice responses in detail, to explain the instructions further, or to answer any questions about the task during this practice round to ensure full comprehension.

Data Analysis

For each participant, ratings across 60 trials were averaged by emotion-type, yielding an average arousal and valence rating for each of the 11 emotions. These ratings were plotted on a Cartesian-coordinate plane to form an affective circumplex for each participant (Y-axis = Arousal, X-axis = Valence). Reference means for each of the emotional faces shown in this task have previously been reported based on average ratings of emotional arousal and valence from a large number of typically-developing adults (15 per photograph) (Russell and Bullock 1985). Our sample of typically-developing adults who rated each photograph is considerably larger than that prior reference sample, and emotional processing in typically-developing adults is presumably the desired outcome of emotional processing in typical and atypical development. Therefore, we decided to use our average Adult TD data as a point of reference for comparison of visual representation of data from the other three groups, even though our statistical analyses treated age as a continuous variable when comparing the two diagnostic groups on circumplex measures. Our Adult TD means were comparable to the original reference means.

Fourier Parameterization of Closed Contours (FPCC)—The conventional point-wise analysis of valence and arousal ratings only provides information about group differences for each individual emotion. Emotion-specific analyses quantify neither the relations between emotions nor how valence and arousal differ as a whole between groups. In the field of quantitative analysis, the Fourier Parameterization of Closed Contours (FPCC) is a well-established method to approximate curves. This elegant technique permits numerical quantification of the entire closed contour of the affective circumplex of each participant using only a few parameters. Those parameters can be compared across diagnostic groups to obviate the need to compare groups on ratings for each individual emotion, which would be contrary to the theory of the circumplex model of affect and which would entail an excessive number of statistical comparisons and the likelihood of false positive findings. FPCC in addition provides a concise, visual representation of the differences in both arousal and valence dimensions for the diagnostic groups. We used

FPCC to construct smooth, closed curves through average arousal and valence ratings of emotions by minimizing least-squares-error. Comparing 2-D contours across groups reveals diagnostic effects that involve global features of the circumplex and its deconstruction into arousal and valence dimensions. Thus, we were able to assess circumplex features not captured by traditional analyses of discrete emotions. In the parameterization, a curve is modeled as a linear combination of sine and cosine terms (Giardina and Kuhl 1977). For each participant, a parameterized closed curve $(X(u), Y(u))$, where $0 \leq u \leq 1$, approximates valence and arousal ratings for all faces. Mathematically, a closed curve is:

$$VALENCE: X(u) = V_0 + \sum_{i=1}^n [V_{\sin i} * \sin(2\pi * i * u) + V_{\cos i} * \cos(2\pi * i * u)]$$

$$AROUSAL: Y(u) = A_0 + \sum_{i=1}^n [A_{\sin i} * \sin(2\pi * i * u) + A_{\cos i} * \cos(2\pi * i * u)]$$

with the constraint that $X(0) = X(1)$ and $Y(0) = Y(1)$, where $i = 1, \dots, n$ and n denotes the n harmonic terms (Kuhl and Giardina 1982). We used up to second-order harmonics to model the smooth, closed curve because setting $n = 2$ provided sufficient flexibility, without spurious sharp changes, to the curve for modeling circumplex data. Optimal values of parameters V_0 , A_0 , $V_{\sin i}$, $A_{\sin i}$, $V_{\cos i}$, and $A_{\cos i}$ were estimated by minimizing least-squares-differences between the fitted curve and the each participant's circumplex data.

Varying the value of each FPCC coefficient corresponds to systematic variations in the circumplex curve (See Figure S2 for illustration). In general terms, because V_0 specifies the center of the curve along the X-axis (valence); changing the value of V_0 translates the curve left or right on the valence axis. Similarly, A_0 specifies the center of the curve along the Y-axis (arousal) and changing its value translates the curves up or down along the arousal axis. Varying $V_{\sin 1}$ alters the range of values (width) of the curve along the X-axis (constriction of range of valence measures), whereas varying $A_{\cos 1}$ alters the range of values (height) of the circumplex systematically along the Y-axis (constriction of range along arousal dimension). Finally, varying the $V_{\cos 1}$ coefficient expands or contracts the circumplex valence ratings in emotions that are at the extremes of arousal (quadrant-specific valence effects), whereas varying $A_{\sin 1}$ expands or contracts the circumplex arousal ratings in emotions that are at the extremes of valence (quadrant-specific arousal effects).

Hypothesis Testing—We tested our hypothesis that arousal and valence parameters determining the shape of the circumplex would vary across diagnostic groups. Diagnosis as a main effect and its possible parameter-specific effects were assessed using a backward, step-wise variable selection procedure for modeling influences on circumplex shape. Statistical procedures were performed using SAS software (V9.2, SAS Institute Inc., Cary, NC). Variable selection was performed using mixed-models analysis with repeated measures of dimension (arousal, valence) and parameter coefficients derived from FPCC. The model included two within-subjects factors: “affect dimension” with two levels (valence, arousal) and “trigonometric parameter” with two levels (sine, cosine). Only first-order sine and

cosine terms were included for the sake of model simplicity and because, compared with other order terms, they accounted for the vast majority of variance between and within groups. We used “diagnosis” (ASD, TD) as the between-subjects factor, and age and sex were included as covariates. FSIQ was also included as a covariate to determine whether IQ influenced our findings. We considered for inclusion all 2-, 3-, and 4-way interactions of diagnosis, age, trigonometric parameter, and dimension. Interactions that were not statistically significant were eliminated via a backward-step-wise-regression, with the constraint that the model had to be hierarchically well-formulated at each step (i.e., all possible lower-order component terms of any interaction were included in the model, regardless of statistical significance). Model selection was determined at each step by the Akaike Information Criterion and Bayesian Information Criterion, with a p value <0.10 required for retention. We calculated and plotted least-squares means and standard errors in the mixed models to aid interpretation of significant findings. We also used least-square means in the model to generate average group contours. All p values were 2-sided.

Exploratory Analyses—We divided participants into four groups by diagnosis and age: Adult ASD ($N = 35$, 4F, Ages: 18–60 years, Mean: 32.9 ± 12 years), Adult TD ($N = 50$, 8F, Ages: 18–61 years, Mean: 30.5 ± 10.2 years), Child ASD ($N = 16$, 2F, Ages: 7–17 years, Mean: 12.5 ± 3.1 years), and Child TD ($N = 30$, 13F, Ages: 7–17 years, Mean: 13.3 ± 2.9 years). Mean FSIQ scores were: Adult ASD (108.91 ± 19.47), Adult TD (116.57 ± 12.17), Child ASD (108.67 ± 23.04), and Child TD (115.23 ± 13.64). We also divided participants by diagnosis alone to compare the entire ASD and TD groups. We conducted multivariate ANCOVAs with estimated parameter coefficients from the FPCC analysis as dependent variables, group as the independent variable, and age and sex as covariates using the general linear model within SPSS20 (SPSS Inc., Chicago, IL).

Multivariate ANCOVAs were conducted with arousal and valence ratings as dependent variables, group as the independent variable, and age and gender as covariates to assess emotion-specific differences between groups. These analyses were also conducted with ASD subtype (PDD-NOS, Asperger’s Syndrome, Autistic Disorder) as the independent variable to determine whether participant responses varied according to specific diagnosis. We used hierarchical multiple regressions for ASD and TD groups (controlling for age and sex) with arousal and valence ratings as dependent variables and FSIQ scores as the independent variable to assess whether IQ was significantly correlated with how participants rated each emotion-type. Similar analyses were conducted with total ADOS scores (Social Affect (SA) + Restrictive, Repetitive Behaviors (RRB), Mean = 11.2 ± 4.4 (Gotham, Risi, Pickles, and Lord 2007). Scores for ASD child participants (7–16 years) who were assessed with ADOS modules 2 and 3 were converted to calibrated severity scores (CSS, Mean = 7.3 ± 1.9), indicating that our child participants ranged in severity from high ASD to high autism (Gotham, Pickles, and Lord 2009). CSS conversion algorithms are not available for participants over the age of 16 or who were assessed with module 4 of the ADOS.

To assess whether severity of diagnosis significantly correlated with how participants rated each emotion-type, we used hierarchical multiple regressions for analyses in the ASD group (controlling for age and sex) in which arousal or valence ratings were entered separately as the dependent variable and total ADOS score was the independent variable. These

regressions were applied separately to each facial stimulus. We also conducted these analyses with only the social affect scores from the ADOS as the independent variable, because we expected the social affect measure alone might correlate more strongly with how participants with ASD rated these affective stimuli. We also used hierarchical multiple regressions with the Social Responsiveness Scale (SRS) total and subscale scores (Social Awareness, Social Cognition, Social Communication, Social Motivation, and Autistic Mannerisms) to discern whether any of these more specific measures of socialization and emotion correlated with arousal and valence ratings in the child participants with ASD.

Finally, we conducted multivariate ANCOVAs with arousal or valence ratings entered separately as the dependent variable, ASD subtype (PDD-NOS, Asperger's Syndrome, Autistic Disorder) entered as the independent variable, and age and gender entered as covariates to assess whether participant responses varied according to specific by ASD subtype.

Results

Hypothesis Testing

Table 2 depicts our final statistical model produced by a variable selection procedure for modeling influences on the circumplex shape which included two within-subjects factors: "dimension" with two levels (valence, arousal) and "trigonometric parameter" with two levels (sin, cos) (Fig. 3). The between-subjects factor was "Diagnosis" (ASD,TD). The main effect of diagnosis was significant at $p < 0.05$, and parameter estimates for diagnosis indicated that, overall, the range of emotional ratings in the ASD group was constricted for the entire circumplex, independent of age and sex (Fig. 3). Covarying for FSIQ yielded no changes in our findings.

To evaluate whether diagnosis effects differed across trigonometric parameters and the valence or arousal dimensions of the circumplex, we assessed significance for the Diagnosis $\times$ Trigonometric Parameter and Diagnosis $\times$ Dimension interactions. The Diagnosis $\times$ Dimension interaction was highly significant ($p = 0.0004$). Post-hoc analyses showed that the interaction was driven by effects in the valence dimension that were significantly less negative in the ASD than TD group ($t_{129} = 3.9$, $p = 0.0001$) (Fig. S3). The interaction Diagnosis $\times$ Trigonometric Parameter was also significant ($p = 0.02$), with post hoc analyses showing that the interaction derived from less negative (smaller absolute values) sine coefficients in the ASD group ($t_{129} = 3.1$, $p = 0.002$). Main effects for age and sex were not significant, nor were their interactions with diagnosis.

Task Performance

In order to determine whether all participants were using the full scale of the 2-D grid to perform the task, and to ensure that group differences in average ratings were not attributable simply to one group having more or less of the range of possible ratings available to them during their responses, we examined the maximum arousal, maximum valence, minimum arousal, and minimum valence rating for each participant and then plotted histograms for each of those values for our four groups. These plots and values

confirm that the full range of the available grid, including its furthest extremes, was used by all groups for ratings of valence and arousal (Fig. S5).

So that we could be as confident as possible that participants were performing the task as instructed and to ensure the face validity of their responses, we first visually compared each individual's arousal and valence ratings qualitatively against the canonical circumplex to ensure that the responses seemed reasonable. Then, assuming that the responses of the healthy adults represent the end product of development, we used the arousal and valence scores from typically-developing adults reported by Russell and Bullock (1985) as reference ratings for "correct" performance by assessing quantitatively the correlations of each individual participant's data with the reference ratings. Our rationale was that an individual responding at random to the stimuli or who was not understanding or following instructions would be unlikely to produce a similar response pattern to the reference ratings. Then, as a subset analysis, we removed participants whose correlations between arousal or valence ratings with the reference values were significant at a $p > 0.2$ (corresponding to a Pearson's $r < 0.4187$). These combined qualitative and quantitative assessments eliminated 13 participants (4 Child ASD, 4 Adult ASD, 5 Child TD) from the subset analysis. Similar to findings from our original analysis with the entire sample ($N = 131$), we detected with this smaller sample ($N = 118$) a main effect of diagnosis ($p < 0.05$). Parameter estimates for diagnosis indicated that, overall, the range of emotional ratings in the ASD group was constricted for the entire circumplex, independent of age, sex, and FSIQ. Additionally, we detected the same highly significant Diagnosis $\times$ Dimension interaction ($p = 0.0001$) in the subset sample as in the original analysis. Also as in the original analysis, this interaction was driven by effects in the valence dimension that were significantly less negative in the ASD than TD group ($t_{114} = 3.39$, $p = 0.001$). Thus, although we were unable to measure task comprehension directly during the scan, the use of pre-scan practice trials and the similarity of results in our subset analysis with those of the original analysis show that the vast majority of our participants were able to understand and perform the task as instructed. Whether the 13 participants who were removed from the subset analysis understood the instructions fully, or whether their responses were simply more variable than those of the larger group, is impossible to say.

Exploratory Analyses Comparing Groups on Individual Fourier Parameters

As previously described, our Adult TD data were used as a point of reference for comparison to the other three groups. Additional comparisons were also conducted to assess differences by diagnosis and between child groups. We detected significant differences on the range of valence ratings ($V_{\sin 1}$) for the group comparisons of TD versus ASD ($F_{3,127} = 5.44$, $p = 0.001$), Adult TD versus Child ASD ($F_{3,62} = 2.89$, $p = 0.04$), Adult TD versus Adult ASD ($F_{3,81} = 3.01$, $p = 0.03$), and Child TD versus Child ASD ($F_{3,42} = 5.25$, $p = 0.004$). These $V_{\sin 1}$ differences were reflected in a smaller radius of the circumplex along the valence axis for participants with ASD (Table S1, Fig. 4a, b, d). Adult TD and Child TD groups differed significantly in quadrant-specific arousal effects ($A_{\sin 1}$) ($F_{3,76} = 4.00$, $p = 0.01$), representing higher arousal ratings for more positively-valenced emotions and lower arousal ratings for more negatively-valenced emotions in the Child TD group (Table S1, Fig. 4c). Differences in range of arousal ratings ($A_{\cos 1}$) were significant for the Child TD versus

Child ASD comparison ($F_{3,42} = 4.77, p = 0.006$) and Adult TD versus Child ASD comparison ($F_{3,62} = 4.20, p = 0.009$), representing a more constricted range of arousal ratings for the Child ASD group (Table S1, Fig. 4a, d). This $A_{\cos 1}$ effect was present at a strong trend level of significance for Adult TD versus Child TD ($F_{3,76} = 2.705, p = 0.05$), indicating a slightly more expanded range of arousal ratings for the Child TD group (Table S1, Fig. 4d). Children with ASD did not differ significantly from adults with ASD.

Emotion-Specific Exploratory Analyses

Findings for emotion-specific exploratory analyses generally support our hypothesis-testing results, in that emotions for the ASD groups along both valence and arousal dimensions were rated as constricted in all their ranges relative to those of the TD groups (Details in Supplementary Materials).

FSIQ, ADOS, and SRS Correlates

Correlations of FSIQ with arousal ratings were similar in both groups, with higher IQ scores associated with more negative arousal scores for low-arousal stimuli (Bored, Contented, Sleepy). Higher FSIQ scores correlated with ‘correctly’ rated, negatively-valenced emotions (Angry, Disgusted, Sad) in the ASD group, whereas FSIQ correlated strongly with ‘correctly’ rated, moderately positively-valenced emotions (Contented, Sleepy) in the TD group (Table S2). Similar regressions conducted for the ASD group showed that ADOS scores correlated at a marginal level of significance with valence ratings for surprise faces ($\beta = 0.315, t_{42} = 2.07, p = .045$); no other significant correlations were found. Additionally, results did not vary by ASD subtype and we found no significant correlations for SRS measures in our participants with ASD.

Discussion

Our findings support the hypothesis that parameters of arousal and valence determining circumplex shape would demonstrate that the range of values on both valence ($V_{\sin 1}$) and arousal ($A_{\cos 1}$) dimensions, and therefore the overall shape of the circumplex, was significantly constricted for participants with ASD. Additional findings (significant interactions for Diagnosis $\times$ Dimension and Diagnosis $\times$ Trigonometric Parameter) indicated the presence of additional constriction of the circumplex along the valence dimension in participants with ASD. Results did not change when we covaried for FSIQ.

Our findings are consistent with and extend those from prior studies that have assessed emotional responses in TD participants and participants with ASD. One study, for example, reported significantly lower measures of autonomic arousal (skin conductance responses) in adults with ASD compared with TD controls when viewing emotional faces (Neutral, Happy, Angry) (Hubert et al. 2009) but not when performing non-emotional tasks (discriminating a person’s age from their face or the direction of an object’s motion). This finding suggests that the reduced arousal in participants with ASD was specific to the emotional content of face stimuli, consistent with our finding that participants with ASD report lower ratings of arousal when viewing emotional faces.

Our findings showing reduced arousal and valence ratings by the ASD group appear to be in contrast to the widely supported polyvagal theory, which posits the existence of a hypersympathetic state for individuals with ASD. However, given that the vast majority of these prior studies were based in the theory of basic emotions, assessing whether these results are directly relatable to our circumplex data is difficult. Most prior studies, for example, included a small number of emotions, and emotions that over-represented emotions with high arousal and negative valence (i.e., Fear, Anger, Disgust) that are positioned typically in the upper left quadrant of the affective circumplex. Emotions with low arousal and positive valence (in the bottom right quadrant of the affective circumplex) have been under-represented in prior studies. The broad range of emotional stimuli in our paradigm and the focus on the two dimensions of arousal and valence may afford us the ability to better disentangle the autonomic effects of affective stimuli.

Previous studies typically have not studied subjective ratings of emotions and have instead used forced choice, matching, or discrimination tasks to assess processing of facial emotions in persons with ASD (Harms et al. 2010). Nevertheless, several have acquired self-report measures of emotional experiences in ASD patients. Consistent with our findings, those studies have generally reported a more limited range of arousal and valence ratings for participants with ASD. One study showed that ratings of the 'pleasantness' of pleasant, unpleasant, or neutral pictures, selected from the International Affective Picture System (IAPS) (Lang et al. 1999) were more limited in range along a pleasant-unpleasant scale (valence) in high-functioning children with ASD compared with TD children (Ben-Shalom et al. 2006). Another, smaller study showed that high-functioning adults with ASD compared with TD controls reported reduced arousal levels when viewing sad pictures from a set of IAPS pictures selected to induce a wide range of emotions (e.g., Fear, Anger, Happiness, Sadness). Unlike the other IAPS stimuli, sadness-evoking pictures were of exclusively social situations, suggesting the possibility that reduced emotional arousal is only associated with social stimuli in persons with ASD (Bolte et al. 2008).

Various explanations may account for why individuals with ASD view less arousal and valence in an emotional face. Persons with ASD may engage in reduced eye contact and attention to faces because faces may be intrinsically less interesting, or may not carry the same informational value for them as for TD individuals. Additionally, reduced social motivation and cue salience may impair the development of expertise for social and emotional cues in children with ASD (Dawson et al. 1998; Klin et al. 2003), thereby decreasing the amount of arousal and valence experienced in response to these cues. Also, the ability to discriminate subtle differences between faces develops during childhood and requires exposure to and interest in those stimuli (Carey 1992); therefore the development of this discriminatory skill may be hampered by an indifference to faces in persons with ASD (Swettenham et al. 1998). Alternatively, children with ASD may avoid mutual eye gaze because it is aversive or overly-arousing (Kylliäinen and Hietanen 2006), which in turn could produce a compensatory muting of emotional responses that reduces the range of valence and arousal experienced by individuals with ASD. Finally, constriction of valence and arousal could be fundamental and primary, and may contribute to some of these other behavioral characteristics of persons with ASD.

A constricted range of valence and arousal when assessing emotions, whether the constricted range is specific to social stimuli or is a more general feature of emotional experience, has important implications for the development of adaptive social and communicative skills in persons with ASD. Prior research suggests that some individuals with ASD perceive 'exaggerated' emotional facial expressions as being more realistic and representative of real-life emotions (Rutherford and McIntosh 2007), consistent with our finding of constricted ranges for valence and arousal ratings in this population. Perhaps some individuals with ASD require more intense social stimuli to elicit a typically-developing level of emotional response. Further research should assess whether persons with ASD who are less able to experience the full range of emotions contributing to social cues and behavioral rewards can benefit from the use of exaggerated emotional gestures and expressions as therapeutic interventions. The disproportionately constricted range of valence in persons with ASD could interfere in particular with reward-based learning, especially in social settings that are rich in social stimuli, because socially-based reinforcement may not be a sufficiently strong incentive. Whether the constricted range of valence and arousal in persons with ASD is also found in response to emotional stimuli that are less social than faces will be important to determine for reward-based interventions in ASD.

Exploratory Findings

No main effects for age were detected in our a priori hypotheses tests, a surprising negative finding given prior research showing developmental differences in emotion recognition and understanding (Batty and Taylor 2006; Russell and Bullock 1985). We conducted exploratory analyses to ensure that we were not missing important developmental effects in circumplex-based ratings of emotional experiences in our participants. In both diagnostic groups, we detected differences between adult and child circumplexes. Also, within children and adults, individuals with ASD were more constricted than their TD counterparts. We may have been unable to detect developmental effects in our a priori hypothesis testing because the F-values for dimension, trigonometric parameter, and dimension $\times$ trigonometric parameter were so large that they obscured age effects.

Exploratory analyses also detected evidence for a correlation of FSIQ scores with participant ratings of arousal for individual emotions that evoke low arousal (higher IQ associated with more negative arousal scores for Bored, Contented, or Sleepy faces). These findings were generally consistent across diagnostic groups (Table S2), suggesting that facial emotions evoking low arousal may be more difficult to understand, perhaps because these stimuli are inherently more emotionally ambiguous and therefore may require more cognitive capacity to rate, which would likely be influenced by overall intellectual ability (Gerber et al. 2008).

Surprisingly, we detected only one significant positive correlation between ADOS scores and valence ratings for individual emotional face stimuli (Surprise, $p = .045$). Overall, results in our participants with ASD did not vary by severity of symptoms based on ADOS scores or SRS measures. This negative finding was somewhat unexpected, given prior studies that have shown an effect of symptom severity on the recognition of emotion in persons with ASD. For example, one study reported that children with ASD who had more severe symptoms (on the Communication and Total subscales of the SRS) made more

emotion recognition errors, particularly in recognizing expressions of anger (Bal et al. 2010). However, because the circumplex model of affect does not rely expressly on the use of emotional labels (i.e., Angry, Happy, etc.) to assess facial emotions, perhaps deficits in the more cognitive components of social responsiveness are not as critical in performance on this task.

Implications for the Neural Underpinnings of Emotional Processing in Persons with ASD

The circumplex model of affect proposes that two distinct neurophysiological systems subserve arousal and valence. One previous study, which collected fMRI data as healthy adults performed the same task used in the present study (Gerber et al. 2008), found that arousal ratings correlated inversely with neural activity in the amygdala complex and right medial prefrontal cortex (mPFC). In contrast, valence ratings correlated inversely with activity in the dorsal anterior cingulate (dACC) and parietal cortices, whereas emotions at the extremes of valence (high positive/high negative valences) were associated with more activity in the amygdala. Given the significant differences between our ASD and TD group in their behavioral responses for the same task, we think it likely that functioning of the circuits that subserve valence and arousal may be atypical in persons with ASD. Although functional imaging studies of emotional processing in ASD have yielded inconsistent findings, several have reported hypofunctioning in regions often associated with social impairments in ASD (i.e., ACC, mPFC, right anterior insula, amygdala) (See Di Martino et al. 2009 for a review). These findings of hypofunctional circuits are generally consistent with our findings that valence and arousal are constricted in the circumplex of our ASD group.

Limitations

One prominent limitation of this study is the absence of eye-tracking data during the participants' viewing of emotional faces. Some prior studies have shown that individuals with ASD do not spontaneously attend to, and they may even avoid, the eyes of other people, even though the eyes are a rich source of information about another person's emotional state (Klin et al. 2002). Less attention to the eyes of our face stimuli conceivably could have impaired the ability of participants with ASD to recognize and rate accurately both valence and arousal when viewing emotional faces (Kliemann et al. 2010). However, we should also note that a number of studies have shown no significant differences between the eye-gaze behavior of individuals with ASD and healthy controls while viewing emotion faces (e.g., Parish-Morris et al. 2013). Without eye-tracking data, we cannot exclude the possibility that subtle group differences in attention to specific facial features influenced our findings. Nevertheless, we are confident for several reasons that participants with ASD were attending to the facial stimuli to a substantial degree. For example, we consider the qualitatively similar behavioral ratings of the ASD group as in the TD adults to be likely indicators of generally "correct" performance, in terms of not only understanding the task, but also in perceiving and rating the face stimuli. Similarly, arousal and valence ratings for each participant correlated strongly with the reference ratings from the TD adults, further suggesting that the participants with ASD attended to the face stimuli in ways sufficiently similar to controls so as to make large, systematic differences in eye gaze during the task unlikely. Moreover, even if those group differences in eye gaze were present, their practical

consequences for face processing, in terms of recognizing and labeling facial emotions, were demonstrably minimal in our data. Finally, even if we could direct the patterns and durations of gaze for each participant during our task, as has been done in several previous studies (e.g., Kuhn et al. 2010), that intervention would not inform us about the differences or similarities across groups in processing facial emotions naturalistically. Further research using eye-tracking is warranted to understand whether differences in ratings of arousal and valence in response to emotional stimuli is a consequence of altered gaze and attention to specific features of the facial stimuli in ASD.

Another limitation of the study is that its cross-sectional design undermines the interpretation of developmental findings, given that developmental trajectories cannot be inferred from cross-sectional data (Kraemer et al. 2000). The more normal-appearing circumplex of adults with ASD than children with ASD in this study, for example, could have derived from preferential ascertainment of higher-functioning adults than children with ASD, whereas a longitudinal study of children with ASD could instead find that their circumplexes when assessed in adulthood are unchanged. Thus, future research on the developmental trajectory of emotional experience in persons with ASD should be prospective and longitudinal, rather than cross-sectional.

It is important to note that the affective circumplex paradigm does not allow us to determine whether individuals with ASD “view” or “perceive” less arousal and valence from their provided ratings, or whether they use language in a way that communicates, or rates, less intensity of emotional experience in our task. However, given the significant group differences in arousal and valence ratings of emotional stimuli and their independence of ratings on the ADOS and SRS, we do suggest that the task provides valuable insight and affords us a novel approach to studying the emotional experiences of persons with ASD that is independent of more standard instruments for assessing socio-emotional experiences in this population. Also, we are aware that our findings cannot be generalized without further study to non-facial emotional stimuli. Indeed, a large body of research suggests that human faces and facial emotions are processed differently from other objects (Piepers and Robbins 2012). Nevertheless, as it is commonly accepted that no emotional cues are more socially salient than faces, we believe that our findings may pertain to socio-emotional processing more generally.

Finally, as is often the case in research on ASD, we struggled when designing our experiment with the tradeoffs between task difficulty, selection of a task that can provide scientifically important data, and the generalizability of the study and its findings to the entire autism spectrum. We considered multiple issues simultaneously. In particular, we needed to include in our study individuals who would and did understand a task that addressed meaningfully our fundamental research questions. Non-verbal individuals, for example, would be unlikely to understand or perform our task adequately. Also, if we had included lower functioning persons with ASD (i.e., those with lower IQs), we would have had to include control participants with comparable levels of intelligence, which in turn would introduce a host of confounding variables and sample heterogeneity that would make interpretation of findings difficult. We were careful to covary for full-scale IQ, as well as for age and sex, and found no significant effects for any of these variables in our main model.

Additionally, the individuals with ASD in our sample ranged in ASD diagnosis from PDD-NOS to Asperger's to Autism (Mean ADOS Score = 11.2), suggesting that we can extrapolate our findings to individuals with moderate to high-functioning ASD.

Conclusions

Our findings provide a window to the emotional life of children and adults with ASD and show that they have a muted and constricted range of emotional recognition and understanding compared with their TD counterparts. Traditional methods of studying emotions that focus on identifying differences between discrete, “basic” emotions are ill-equipped to capture the blunted emotional experiences across the entire spectrum of emotions for persons with ASD. Our work has important implications for improving reward-based learning and interventions in ASD, as a constricted range of valence and arousal may interfere with the assignment of positive-reward value to social stimuli. Valence and arousal measures may be useful in tracking treatment responses to intervention aimed at promoting social cognition, in which successful treatment might be expected to expand the range of the circumplex in persons with ASD. Finally, the valence and arousal ratings provide dimensional measures to examine correlates of emotion in neuroimaging, electrophysiological, and genetic studies of ASD.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This work was supported in part by NIMH grants MH36197, and MHK02-74677, T32-MH16434, T32-MH18264, funding from the National Alliance for Research on Schizophrenia and Depression, and the Suzanne Crosby Murphy Endowment at Columbia University.

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Fig. 1.

A graphical representation of the circumplex model of affect with the *horizontal axis* representing the valence dimension and the *vertical axis* representing the arousal or activation dimension

Fig. 2.

Affective CircumplexTask Each trial consisted of three components presented in succession: (1) Visual presentation of an emotional face for 18 s; (2) Visual presentation of a 2-D grid on which participants indicated their ratings of arousal and valence for each face by moving an arrow controlled by a computer mouse. This screen remained visible until the participant clicked the mouse button, up to a maximum of 20 s; (3) Visual presentation of a fixation point (+) at the center of the participant's visual field. The fixation point was displayed immediately following the rating of valence and arousal. The durations of rating and gaze fixation were each variable, but when summed together always equaled 20 s. Each run consisted of 20 trials presented in a pseudorandom order (but uniform from subject to subject), and we acquired three runs (totaling 60 stimulus trials) for each person

Least Square Means							
Effect	Dx	Trig	Dim	Estimate	Std. Error	$t_{(35)}$	Pr > t
Dx*Trig*Dim	ASD	cos	Valence	1.0245	0.1353	7.57	<.0001
Dx*Trig*Dim	ASD	cos	Arousal	2.0316	0.1353	15.01	<.0001
Dx*Trig*Dim	ASD	sin	Valence	-2.4876	0.1353	-18.38	<.0001
Dx*Trig*Dim	ASD	sin	Arousal	0.3779	0.1353	2.79	0.006
Dx*Trig*Dim	NC	cos	Valence	0.7614	0.1064	7.16	<.0001
Dx*Trig*Dim	NC	cos	Arousal	2.3126	0.1064	21.74	<.0001
Dx*Trig*Dim	NC	sin	Valence	-3.1725	0.1064	-29.83	<.0001
Dx*Trig*Dim	NC	sin	Arousal	0.3019	0.1064	2.84	0.0053

Fig. 3.

TD and ASD group curves were plotted using the least square means generated from the 3-way interaction of Diagnosis $\times$ Trigonometric Parameter $\times$ Dimension (Dx $\times$ Trig $\times$ Dim) for $V_{\sin 1}$, $V_{\cos 1}$, $A_{\sin 1}$, and $A_{\sin 1}$ and the mean group coefficients for V_0 , A_0 , $V_{\sin 2}$, $V_{\cos 2}$, $A_{\sin 2}$, and $A_{\sin 2}$ derived from the FPCC analysis. Overall, compared to the TD group, the range of emotional ratings in the ASD group was constricted for the entire circumplex

Fig. 4.

Group Comparison FPCC Analysis Curves: **a–c** The parametric closed curve for the Adult TD group is contrasted with curves constructed using (a) the V_{sin1} and A_{cos1} coefficients for the Child ASD group which shows constriction for valence and arousal dimensions (b), the V_{sin1} coefficient for the Adult ASD group which shows constriction for the valence dimension (c), and the A_{sin1} and A_{sin2} coefficients for the Child TD group which shows quadrant-specific arousal effects. **d** The parametric closed curve for the Child TD group contrasted with curves constructed using the V_{sin1} and A_{cos1} coefficients for the Child ASD group (while holding the other Child TD values constant) shows constriction of valence and arousal for the Child ASD group

Table 1

Participant characteristics

	ASD	TD
Participants (N)	51	80
ASD Subtype:		
PDD-NOS	10	–
Asperger's syndrome	20	–
Autistic disorder	21	–
Mean age (years)	26.5	24.1
Children (<18 years) (N/%)	16 (31 %)	30 (38 %)
Males (N/%)	45 (88 %)	59 (74 %)
Caucasian (N, %)	39 (76 %)	58 (73 %)
Mean SES ^a	50	53
Mean FSIQ ^b	110.9	116.1
Mean ADOS (Social affect + restrictive, repetitive behaviors) ^c	11.2	–

^aSES scores for 7 TD and 14 ASD participants were unavailable

^bFSIQ scores for 1 TD participant and 3 ASD participants were unavailable

^cADOS scores for 6 ASD participants were unavailable

Table 2

Final statistical model

Effect	DF	F-Value	Pr > F
Sex	1,127	0.03	0.86
Age	1,127	0.01	0.9301
Diagnosis	1,127	4.08	0.0456
Trigonometric parameter	1,129	1,234.14	<.0001
Dimension	1,129	791.6	<.0001
Trigonometric parameter × dimension	1,130	151.48	<.0001
Diagnosis × trigonometric parameter	1,129	6.06	0.0151
Diagnosis × dimension	1,129	13.29	0.0004

Model produced by variable selection procedure for modeling influences on circumplex shape which included two within-subjects factors: “dimension” with two levels (valence, arousal) and “trigonometric parameter” with two levels (sin, cos) (Fig. 2). “Diagnosis” (ASD, TD) was the between-subjects factor