Published in final edited form as:

J Autism Dev Disord. 2015 August ; 45(8): 2594–2612. doi:10.1007/s10803-015-2429-2.

Patterns of Sensitivity to Emotion in Children with Williams Syndrome and Autism: Relations Between Autonomic Nervous System Reactivity and Social Functioning

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Abstract

Williams syndrome (WS) and autism spectrum disorder (ASD) are associated with atypical social-emotional functioning. Affective visual stimuli were used to assess autonomic reactivity and emotion identification, and the social responsiveness scale was used to determine the level social functioning in children with WS and ASD contrasted with typical development (TD), to examine syndrome-specific and syndrome-general features. Children with ASD exhibited the highest arousal in response to faces, with a lack of difference in autonomic sensitivity across different emotional expressions, unlike in WS and TD. The WS group demonstrated unique deficits in identifying neutral stimuli. While autonomic responsivity to neutral faces was associated with social functioning in all children, converging profiles characterized children with WS contrasted with TD and ASD.

Keywords

Autonomic nervous system; Emotion; Autism spectrum disorder; Williams syndrome; Social behavior; Social functioning

Introduction

While atypical social behavior characterizes many congenital neurodevelopmental disorders, there is limited understanding of the early manifestations of social impairments, including their associations with autonomic nervous system (ANS) reactivity. Williams syndrome (WS) is a rare developmental disorder with an estimated prevalence rate of 1:7,500 live

births (Strømme et al. 2002), caused by a contiguous deletion of 25–28 genes on chromosome 7 (Ewart et al. 1993; Hillier et al. 2003). The social profile of WS is characterized by an unusually high drive to socially interact with others, a bias toward viewing and an augmented skill in recognizing faces, and idiosyncratic language features that facilitate social engagement (see Järvinen et al. 2013; Järvinen-Pasley et al. 2008; Martens et al. 2008; Haas and Reiss 2012, for reviews). These unusual social attributes combine with a full-scale IQ profile characterized by the mild-to-moderate intellectual disability range (mean of 50–60) (Searcy et al. 2004; Mervis et al. 2000), although there is substantial heterogeneity in skills tapping into both cognitive (perception, attention, spatial construction, and social-emotional ability) (Porter and Coltheart 2005) and social (social approach tendency, facial emotion recognition, in conjunction with response inhibition) (Little et al. 2013) functions. By contrast, autism spectrum disorders (ASD) are pervasive developmental disorders characterized by significant deficits in communication, reciprocal social interaction, and restricted and repetitive interests (APA 2000). However, as the diagnosis of ASD is behaviorally rather than genetically determined, substantial heterogeneity in the clinical presentation exists, including the level of intellectual function that may range from severe disability to above average. Consequently, under the broad umbrella of ASD comprises heterogeneous etiologies, and presently understanding between such and pathophysiological and clinical manifestations is lacking (Cohen et al. 2013). Social behavior is typically associated with the avoidance of social interactions, a lack of social-emotional reciprocity, and reduced eye contact (Lord et al. 2000; Klin et al. 2002). Thus, current evidence suggests that the social and cognitive profiles associated with both WS and ASD are far from uniform.

Social Functioning

While impaired social functioning is a core diagnostic feature of ASD, serious problems in social communicative behavior are evident in individuals with WS as well despite their “hypersociability”. For example, Klein-Tasman et al. (2007) used the Autism Diagnostic Observation Schedule (ADOS; Lord et al. 1999), and found that approximately one half of their sample of 2–5 year-old children with WS showed difficulties in various social interaction behaviors, to then extent that their profile both in terms of the constellation and severity of symptomatology overlaps with social-communicative impairments associated with pervasive developmental disorder-not otherwise specified (Klein-Tasman et al. 2009). A recent body of empirical studies has specifically focused on delineating the socio-communicative impairments in individuals with WS employing the Social Responsiveness Scale (SRS; Constantino and Gruber 2005). For example, Klein-Tasman et al. (2011) administered the SRS to parents of 4–16 year-olds with WS. The results showed that more profound impairments pertained to social cognitive domains (communication and cognition) than to pro-social functions (social awareness and motivation) in their sample of children with WS. Riby et al. (2014) found that similarly to Klein-Tasman et al. (2011), only ~17 % of individuals with WS ages 6–36 years were found to function within the normative range on the SRS, suggesting that approximately 80 % of the WS population exhibit severe social-communicative deficits. As an extension to these studies, van der Fluit et al. (2012) utilized the SRS in concert with an experimental social attribution paradigm to examine associations between social cognition, social perception, and social communication in 8–15 year-olds

with WS. On the SRS, the most severe deficits were observed in social cognition, while social motivation appeared unimpaired in those with WS. The results further highlighted that individuals with WS who performed similarly to TD individuals in interpreting ambiguous social dynamics also demonstrated fewer parent-reported social reciprocity difficulties in real life. Notably, these associations remained after controlling for intelligence, suggesting that problems with interpreting social situations may contribute to interpersonal difficulties of individuals with WS beyond the level of intellectual functioning. However, all above-discussed studies were within-syndrome investigations and thus included no control group. While important, they fail to elucidate syndrome-specific and general features across different neurodevelopmental conditions, as well as normative profiles, which promise to have some clinical utility

Social Perceptual Ability

WS and ASD have been shown to be associated with opposite preference patterns with respect to orienting to social versus non-social information in eye tracking studies (Riby and Hancock 2008, 2009). In the case of WS, social information appears atypically salient for such individuals, manifesting as an attentional bias toward social over nonsocial stimuli both in social interaction contexts (e.g., Järvinen-Pasley et al. 2008; Laing et al. 2002) and experiments (Riby and Hancock 2008, 2009), as well as more competent cognitive processing of social than non-social stimuli (Järvinen-Pasley et al. 2010). In addition, functional MRI (fMRI) evidence indicates that individuals with WS demonstrate striking valence-specific neural activation patterns to affective non-social and facial images, associated with reduced amygdala and orbitofrontal cortex (OFC) activation in response to negative (fearful) face stimuli as compared to TD controls, while activation to fearful non-social scenes is drastically increased (Meyer-Lindenberg et al. 2005). Similarly, combined event-related potentials (ERP) and fMRI evidence shows that brain responses to positive facial expressions are enhanced in WS (Haas et al. 2009; Mills et al. 2013). These data raise the possibility that the valence-specific response patterns observed at the neurobiological level may also manifest at the level of ANS activation.

The opposite profile associated with heightened salience and enhanced processing of non-social over social information has been suggested to characterize individuals with ASD (Sasson et al. 2012; Klin et al. 2002). Both disorders share the fact that the underpinnings of the atypically heightened salience of variably social and non-social information are currently poorly understood (Sasson et al. 2012); thus, comparing psychophysiological responses to these two classes of stimuli may elucidate such mechanisms.

The atypical attentional patterns toward social stimuli associated with WS (Järvinen-Pasley et al. 2008; Mervis et al. 2003) and ASD (Osterling and Dawson 1994; Osterling et al. 2002) may contribute to difficulties with interpreting emotional cues from faces associated with both syndromes. Only a few known studies have compared the processing of facial affect in children with WS and ASD. Riby et al. (2008) tested participants with WS, ASD, and developmental delay (DD) matched for verbal mental age (VMA) and nonverbal ability on an emotion recognition task. While children with WS performed at a higher level than both control groups of DD children, those with ASD performed less accurately than the controls

matched for nonverbal ability. In another study, Lacroix et al. (2009) used a task of facial affect labeling, and found no between group differences in performance. Their sample included children with WS, VMA-matched children with ASD, and TD children matched to the clinical groups on sex and VMA. These findings are largely in agreement with the broader affect processing literature of WS, typically indicating that while individuals with WS perform at a significantly poorer level as compared to chronological age (CA)-matched TD controls, they score at the level expected for their MA (Gagliardi et al. 2003; Plesa Skwerer et al. 2005; Plesa Skwerer et al. 2006). Studies of facial expression processing in individuals with ASD have provided mixed results, varying from poorer performance relative to CA-matched TD controls to similar levels of performance to TD controls matched for VMA or full-scale intelligence quotient (FSIQ) (see Harms et al. 2010, for a review). Taken together, these studies suggest heterogeneous affect processing ability in individuals with ASD, which may reflect the variable level of cognitive function associated with the syndrome as well as the wide range of age groups studied. By contrast, in WS, these abilities appear more consistently MA-level appropriate.

Autonomic Nervous System (ANS) Functioning in WS and ASD

Indices of ANS function, such as electrodermal activity (EDA) and heart rate (HR), are amygdala-associated non-invasive measures that reflect sensitivity to social-affective information at physiological levels (Adolphs 2001; Laine et al. 2009). Changes in EDA may index the arousal or intensity of motivationally meaningful stimuli (Lang 1995), for example, threatening or startling information, feelings of aggression and defense, and positively and negatively valenced affective events have been linked to such changes (Bradley et al. 1996; Lang et al. 1998). In TD individuals, images of faces as compared to non-social objects result with elevated sympathetic response as indexed by skin conductance level (SCL) (Hirstein et al. 2001). Given that both WS and ASD are associated with aberrant social processing, together with divergent attentional profiles to social versus non-social stimuli evident early on in development (e.g., Jones et al. 2008; Klin et al. 2002; Mervis et al. 2003), measuring autonomic responsivity across social and non-social domains would allow the determination of the extent to which affect processing impairments in individuals with WS and ASD may be specific to the social domain.

While social behavior has been linked to patterns of ANS function in both typical and atypical development (see Benevides and Lane 2013; Järvinen and Bellugi 2013; Quintana et al. 2013, for reviews and discussion), research directly contrasting WS and ASD is sparse. Empirical literature on ANS function in ASD has provided extremely disparate findings; however, taken together, hyperarousal both in terms of stronger ANS responses to face stimuli, and generalized arousal states, are common observations (Bal et al. 2010; Barry and James 1988; Palkovitz and Wiesenfeld 1980; Hirstein et al. 2001; Kylliäinen and Hietanen 2006). Hypoarousal combined with blunted ANS responsivity has been reported by Hirstein et al. (2001) and Hubert et al. (2009). Hirstein et al. (2001) identified a subgroup of children associated with diminished ANS responses. The majority of children with ASD failed to show any differences in arousal to their mothers' face and to a plain paper cup, highlighting a lack of autonomic reactivity to social as compared to non-social stimuli in these children. In a similar vein, Cohen et al. (2013) utilized stimuli comprising social and non-social

emotion-evoking images and found that individuals diagnosed with idiopathic ASD were associated with parasympathetic dysregulation, autonomic imbalance, and low vagal tone. In addition, electrodermal responses of these individuals showed the largest activity to positively valenced social stimuli, and the smallest response to negatively valenced social stimuli, with no reported between condition (social vs. non-social) effects.

In addition to the above patterns of results, some studies have reported indistinguishable ANS function between participants with ASD and controls (Ben Shalom et al. 2006; Joseph et al. 2008). In line with Hirstein et al.'s (2001) study, Schoen et al. (2008) also divided their sample of children with ASD into subgroups based on their resting skin conductance levels (SCLs), and these were linked to differential responsivity to non-social stimuli; however, the study did not include a control group. In a recent study (Mathersul et al. 2013), SCL baselines of adults with ASD were linked to their behavioral profiles constructed, e.g., on the basis of basic emotion identification ability. Although the mean SCLs were indistinguishable between the ASD and TD control groups, the ASD group represented two distinct subgroups: those with significantly lower than typical SCL and those with more typical SCL. Interestingly, the participants with ASD with lower than typical SCLs demonstrated significant social behavioral impairments, while those with more typical ANS function showed no significant deficits, as compared to TD controls. This study thus began to elucidate potential physiological explanations for the mixed evidence on emotion processing skills in individuals with ASD. It is possible that SCL functioned as biological feedback to aid social-affective behaviors in individuals with ASD in the above-described study.

The small body of empirical literature in WS examining electrodermal and/or HR based indices in response to visual stimuli have also produced mixed results (see Järvinen and Bellugi 2013, for a recent review). For example, Plesa Skwerer et al. (2009) documented hypoarousal in response to dynamic face stimuli, together with more pronounced HR deceleration, which was interpreted as indexing heightened interest in such stimuli, in adolescents and adults with WS in relation to CA-matched controls with TD and DD. Doherty-Sneddon et al. also found that while individuals with WS displayed general hypoarousal as indexed by EDA and reduced gaze aversion in a naturalistic context, similar to the TD controls, their arousal elevated in response to face stimuli (Doherty-Sneddon et al. 2009). Our previous findings from adults with WS contrasted with a TD group showed that when viewing affective face stimuli, individuals with WS demonstrated increased HR reactivity, and a failure for EDA to habituate, suggesting increased arousal (Järvinen et al. 2012). It was further speculated that the lack of habituation may be linked to the increased affiliation and attraction to faces characterizing the syndrome.

Only one known study has contrasted ANS reactivity in individuals with WS and ASD; however, due to the participants with WS being significantly older than those with ASD, the experimental groups were matched to separate control groups of TD individuals on the basis of CA (Riby et al. 2012). Here, SCL reactivity in response to live and video-mediated displays of happy, sad, and neutral affect was measured, and the results showed that only live faces increased the level of arousal for those with WS and TD. Participants with WS displayed lower SCL as compared to the TD group, which the authors interpreted as

suggesting hypoarousal in this group. By contrast, individuals with ASD failed to show the typical increase in SCL in response to live versus video-mediated faces. While the WS group showed the lowest overall SCL, the baseline ANS function of the ASD group was also markedly lower than that of TD controls. Taken together, although existing evidence on the ANS function in WS and ASD is inconclusive, most studies appear to suggest generally lower than typical arousal level in WS while individuals with ASD are typically characterized by the opposite pattern, with variable reactivity to face stimuli. In light of the significant heterogeneity in findings in both WS and ASD in the domains of ANS functioning and social-emotional behavior, further investigations are warranted. It is specifically interesting to examine ANS activity as a potential regulator of associations between emotion processing profiles and social functioning in WS and ASD contrasted with TD. To our knowledge, no previous studies have directly compared individuals with WS and ASD across these multiple domains.

The Current Study

The aim of the present study was to determine whether unique profiles of behavioral and ANS responses to social and non-social emotional stimuli could be identified between individuals with WS, ASD, and TD. Further, as an extension to previous studies and an attempt to elucidate potential sources of heterogeneity evident in both emotion processing and ANS literature to date in both WS and ASD, we also sought to investigate how emotion processing profiles within the social domain were related to the participants' level of social functioning as indexed by the SRS (cf. van der Fluit et al. 2012; Riby et al. 2014; Klein-Tasman et al. 2011). All participants with ASD were classified as high-functioning, to ensure they were able to complete the experimental task, and to restrict potential heterogeneity in affect processing that may be simply due to the variable level of within-syndrome cognitive functioning. The rationale for incorporating both social and non-social stimuli in the experimental paradigm was that in addition to the contrasting profiles of orientation to social stimuli that are suggested to characterize WS and ASD discussed above, a bulk of previous investigations employing similar stimuli have identified specific response patterns in both WS and ASD (e.g., Meyer-Lindenberg et al. 2005; Hirstein et al. 2001; Jarvinen et al. 2012), which will ease the interpretation of the current results in the broader context.

Based on the evidence to date, we hypothesized that there would be an association between the sensitivity to socially relevant emotion and social functioning (as measured by the SRS) in ASD and WS. Drawing on the literature indicating divergent patterns of baseline ANS activity in ASD and WS, we hypothesized that more normal (i.e., lower) autonomic response to social (i.e., face) information would be associated with more normal social functioning in children with ASD (cf. Mathersul et al. 2013). By contrast, for individuals with WS, who typically show lower than normal autonomic baseline function, we predicted that higher, i.e., more typical autonomic response may be related to more normal social function. We further hypothesized that children with WS would show lower levels of affect identification performance as compared to the TD group, while ASD and TD groups may be associated with similar levels of emotion identification performance after controlling for FSIQ. With respect to the SRS, we predicted that children with WS and ASD would be associated with

significant social dysfunction. In terms of ANS sensitivity, we hypothesized that relative to the TD controls, children with WS would demonstrate lower levels of arousal, while those with ASD would show highest levels of ANS activity of all groups. We further hypothesized that based on the extant literature, both ASD and WS may be associated with heterogeneous ANS reactivity. While ANS function is substantially less explored in WS relative to ASD, in light of the heterogeneity at the behavioral level reported in WS (Porter and Coltheart 2005; Little et al. 2013), it seems a reasonable expectation that heterogeneous ANS functioning may indeed be observed at least if large cohorts of individuals with WS were studied. Thus, social functioning was included as a measure to explore its potential role in social-perceptual ability and autonomic activity to social-emotional stimuli in children with WS and ASD contrasted with TD.

Methods

Participants

A total of 52 children participated in the study: 12 children with WS (2 males), 17 children with ASD (13 males), and 20 TD control children (8 males). The genetic diagnosis of WS was established using fluorescence in situ hybridization (FISH) probes for elastin (ELN), a gene invariably associated with the WS microdeletion (Ewart et al. 1993). In addition, all participants with WS exhibited the medical and clinical features of the WS phenotype, including cognitive, behavioral, and physical features (Bellugi et al. 2000). All participants were recruited as a part of a multisite multidisciplinary program of research addressing hierarchical levels of neural and cognitive processing in children with different neurodevelopmental disorders. The inclusion criteria for the children with high functioning form of ASD were as follows: monolingual English speaking; idiopathic/non-syndromic autism diagnosed by the ADOS (Lord et al. 1999) and/or the Autism Diagnostic Interview-Revised (ADI-R) (Lord et al. 1994) criteria; ability to participate in cognitive testing; and PIQ portion of the WISC-III above 70. The TD and ASD groups were recruited through the University of California, San Diego (UCSD), while the participants with WS were enrolled through the Laboratory for Cognitive Neuroscience (LCN) at the Salk Institute for Biological Studies. The TD children were screened for history of brain trauma, psychiatric concerns, and central nervous system disorders, and were required to be native English speakers.

In light of the reasonably large corpus of studies indicating linkages between MA level and emotion perception capacity in standard tasks in children with neurodevelopmental conditions (e.g., Gagliardi et al. 2003; Plesa Skwerer et al. 2005, 2006), FSIQ level will be entered as a covariate in the analyses of emotion processing data to account for the lack of a MA matched group for the participants with WS and ASD.

Materials

Cognitive Functioning—The participants' cognitive functioning was assessed using the Wechsler Intelligence Scale for Children (WISC-III) (Wechsler 1991). Participants were screened for multiple criteria. All participants are native English speakers with normal or corrected vision, and none had a history of brain injury. Written informed consent and assent

were obtained from the participant and their caregivers prior to our study. Experimental protocols were approved by the Institutional Review Board at the Salk Institute and at the UCSD. Two TD children were excluded from data analyses as they scored in the clinically significant range on the SRS, indicative of severe social dysfunction.

Table 1 shows the demographic characteristics of the final sample of participants with WS, ASD, and TD. The participants did not differ in terms of CA ($F(2, 48) = .95, p = .39$). The experimental groups scored significantly differently on VIQ ($F(2, 48) = 37.60, p < .001, \eta^2 = 0.62$), PIQ ($F(2, 48) = 45.69, p < .001, \eta^2 = 0.67$), and FSIQ ($F(2, 48) = 62.56, p < .001, \eta^2 = 0.73$). As expected, both the TD and ASD groups scored significantly higher on VIQ, PIQ, and FSIQ as compared to the WS group (all p values $< .001$). The TD group scored significantly higher as compared to the ASD group on VIQ ($p = .001$) and FSIQ ($p < .001$), while the groups did not differ on PIQ ($p = .07$).

In psychophysiology analyses, emotion identification accuracy was a factor controlled in our modeling approach as the ANS activity was recorded passively, independent of the active responses, which may convolute the data. However, unlike in behavioral analyses, IQ differences between groups were not controlled for as it has been suggested controlling for IQ does not contribute to the clarity of the meaningful differences seen in the autonomic responses to valence and social content in individuals with neurodevelopmental conditions (see Cohen et al. 2013, for a discussion). Specifically, it has been postulated that IQ impairments may stem from shared ANS alterations that lead to the social-emotional processing deficits, and thus, it could be argued that social-emotional processing difficulties are not caused by IQ but rather have a shared origins rooted in the underlying neurodevelopmental disorder (Dennis et al. 2009). This sample comprised 11 children with WS (2 males; mean age = 11.63, SD = 1.56), 17 children with ASD, and 20 TD participants (sample as above) (data from one child with WS were removed from analyses due to excessive recording artifacts).

Experimental Measure—The experimental paradigm contrasted emotion processing across standard face and non-social (scene, object) stimuli. For the social condition, the visual stimuli comprised 24 standardized images of facial expression taken from the Mac Brain/NimStim Face Stimulus Set (Tottenham et al. 2009). The experimental stimuli included the following emotions: fearful, happy, and neutral. Happiness is a social emotion that is embedded in social interactions, while fear has direct physiological and evolutionary relevance. Neutral images were included as a control condition. Neuroimaging evidence indicates that each of these emotions is associated with distinct neural systems (e.g., Breiter et al. 1996; Hariri et al. 2002; Morris et al. 1996; Phan et al. 2002; Sommerville et al. 2004). There were eight faces (four male and four female) for each of three emotions (happy, fearful, and neutral). The faces with the highest validation ratings were selected. For the non-social condition, 24 different images from the International Affective Picture System (IAPS) (Lang et al. 1995) depicted affective scenes and objects; there were eight pictures for each of three emotions (happy, fearful, and neutral). None of the non-social images contained human faces. However, given the relatively limited number of non-social images that do not include human faces in the IAPS set, it was necessary to include pictures of animals. Examples of images include dolphins and hot air balloons for happy emotion, shark

and sinking ship for fearful emotion, and mug and basket for neutral emotion. Figure 1 displays examples of the test stimuli. The inclusion of these images as test stimuli is consistent with a body of previous studies examining the neural and psychophysiological underpinnings of emotion processing in humans (e.g., Hariri et al. 2002; Baumgartner et al. 2006; Meyer-Lindenberg et al. 2005). Consistent with our earlier studies (Järvinen et al. 2012; Järvinen-Pasley et al. 2010), a pilot study to facilitate the selection of the nonsocial images was carried out. The images that most reliably conveyed the intended emotion and had the greatest intensity ratings were selected as the test stimuli (except for the neutral condition, for which images associated with lowest intensity were selected). More detailed description of the actual test stimuli has been provided elsewhere (Järvinen et al. 2012).

Psychophysiology Recordings and ANS Measures—EDA and electrocardiogram (ECG) measures were recorded during the passive viewing portion of the experimental paradigm (see procedure below) using BioPac MP150 Psychophysiological Monitoring System (BioPac systems Inc., Santa Barbara, CA) at a 1000 Hz sampling rate.

Raw ECG signal has been filtered and used to calculate HR and inter-beat interval (IBI) measures, after classifying the R peaks of the heart beat cycles. Besides the mean HR and IBI, we extracted the standard deviation of the interbeat interval (sdIBI) to assess variability in heartbeats for each experimental condition, as suggested by Mendes (2009). Quantification of the mean IBI is used in conjunction with mean HR since it is a more sensitive and direct measure of parasympathetic and sympathetic systems activity (Bernston et al. 1995).

For all ANS measurements, we sampled seven seconds subsequent to stimuli presentation and a three-second prestimulus baseline on a trial-by-trial basis, in order to compute event-related change scores. This approach allowed us to obtain weighted trial-specific percentage variations of autonomic activity, thus minimizing the influence of large-scale tonic fluctuations and assessing small-scale ANS reactivity and sensitivity.

Measure of Social Functioning—The Social Responsiveness Scale (SRS) (Constantino and Gruber 2005) is a 65-item parental inventory targeting children ages 4–18 years to identify symptoms of ASD. These include atypical communication, interpersonal relationships, and the presence of repetitive/stereotypic behaviors. While the SRS has specifically been developed to screen for ASD, it is also useful in identifying individuals with problem behaviors whose level of functioning in the targeted domains fall at sub-threshold levels. The caregivers' responses to questionnaire items result in T-scores across the scales: Social Awareness, Social Cognition, Social Communication, Social Motivation, and Autistic Mannerisms, in addition to a Total Score. T-scores below 60 indicate no clinically significant concerns in social functioning; T-scores of 60–75 indicate mild-to-moderate social dysfunction; and T-scores higher than 76 indicate severe social dysfunction.

Procedure

Experimental Measure—To prevent autonomic habituation effects, the psychophysiological (i.e., passive) portion of the study was always administered first, followed by the behavioral affect identification portion. The experiment was conducted in a

quiet room. Participants sat in a comfortable chair in a well-lit room, 130 cm away from a TFT monitor (screen resolution of 1680×1050 pixels). The experiment had two parts: a passive version, which was invariably administered first (for psychophysiological measurement), and an active task, during which participants made affect identification judgments for the same stimuli. The stimuli were presented on a desktop computer running MATLAB (The MathWorks Inc., Natick, MA), which delivered a digital pulse embedded in the recording at the onset of each stimulus. To measure physiological responses, after a fixation cross for 1000 ms, each stimulus was presented for 5000 ms, separated by an interstimulus interval (ISI) of 9000 ms (blank screen). The stimuli were organized with respect to both stimulus type (social/non-social) and affective valence (fearful/happy/neutral) into two pseudorandom sequences, and were preceded by a blinking fixation cross. Stimulus blocks were counterbalanced within experimental groups. Participants were told that pictures of faces and scenes/objects/animals would appear on the screen in a random order. For the passive task, participants were only instructed to look at the pictures carefully, while remaining as quiet and still as possible. For the active task, participants were shown the same stimuli again, and asked to identify the emotion depicted by the stimuli at a forced-choice response screen. Prior to the onset of the active task, the experimenter showed the response screen to the participant, which listed the three possible emotions to ensure that the participant understood each of the emotion options (scary/scared, happy, and “no emotion” as a label for neutral). The participants responded verbally, and the experimenter operated the computer keyboard on the participant’s behalf. After each behavioral trial, participants were asked to identify the gender of the faces, and the scene/object name to ensure that attention was maintained to the stimuli throughout the task. No group differences were observed in post-trial questions (however, as noted, response accuracy was controlled for in the psychophysiological analyses).

Psychophysiological Recording—Ag/AgCl electrodes were applied to the skin with an isotonic NaCl electrolyte gel placed on the index and middle medial phalanges of the participant’s non-dominant hand to record EDA, according to a standard bipolar placement (Venables and Christie 1980). ECG was recorded from Lead II with two disposable electrodes, one attached to the right forearm and the other attached to the left ankle, below the true ankle joint. The recording sessions were divided into four sub-blocks separated by brief pauses, during which participants were allowed to stretch and relax, while recordings were checked for misplacement and movement artifacts. The children were closely observed during the experiment with a hidden video camera that was placed above the stimulus presentation monitor to ensure that the experimenter was able to monitor whether the children showed proper attention to the stimulus screen. Additionally, the examiner observed the participants to note the presence of any excessive movement. The examiner redirected the children to attend to the stimulus and remain still when needed. The sessions were also preceded by a 5-min baseline period, during which ANS activity at rest was qualitatively inspected and participants were given the time to habituate to the sensors. During the experiment, stimulus onsets were marked with trigger codes, embedded into the recordings.

Results

Behavioral Emotion Identification

Figure 2 displays the percentage of correct identifications (derived from raw scores) within each emotion category (fearful/happy/neutral) across the social and non-social stimulus conditions for participants with WS, ASD, and TD (total number of trials per affect category = 8).

The emotion identification data were analyzed by a $2 \times 3 \times 3$ repeated-measures ANCOVA, with the condition (social/non-social) and emotion (fearful/happy/neutral) entered as within-participants factors, and group (WS/ ASD/TD) as a between-participants factor. Due to both VIQ and FSIQ correlating positively with overall emotion identification performance for both the WS and ASD groups (Pearson, two-tailed; all $p > .02$), FSIQ was entered as a covariate. In this analysis, a significant emotion by group interaction emerged ($F(4, 90) = 3.32, p = .014, \eta^2 = 0.13$). Expectedly, there was also a significant main effect of FSIQ ($F(1,45) = 5.47, p = .024, \eta^2 = 0.11$). Post hoc one-way ANOVA with FSIQ entered as a covariate indicated that the interaction was due to between-group differences in identifying neutral expressions ($F(2, 45) = 3.67, p = .034, \eta^2 = 0.14$). Performance with both fearful ($F(2, 45) = 1.03, n.s.$) and happy ($F(2, 45) = .85, n.s.$) stimuli failed to produce significant differences between groups. Pair-wise comparisons indicated that while the TD and ASD groups did not differ in identifying neutral expressions ($p = .90$), performance of the WS group was poorer than that of children with both TD ($p = .05$) and ASD ($p = .01$).

Given the imbalanced gender distribution particularly of the WS and ASD samples, any gender differences in emotion identification performance were investigated. No such effects emerged for any experimental group (all p values $> .08$).

ANS Measures and Statistical Analyses

Autonomic event-related change scores were analyzed by utilizing a linear mixed-effects models approach. Statistical analyses were run and checked using *R* (R Development Core Team 2008), and the *R* package *nlme* (Pinheiro et al. 2013). The models were designed to account for random effects due to between-participant individual differences as well as potential confounding covariates, such as gender and age. Further, we controlled for affect identification proficiency (measured as individual accuracy on the behavioral identification task) in order to account for potential confounding effects of inter-individual differences in conscious emotion recognition skills. Moreover, all trials containing outliers—i.e., those that exceeded 2.5 SDs above or below the individual mean—were removed from analyses in order to minimize the influence of potential residual recording artifacts. Group (WS/ASD/TD), condition (social/nonsocial), emotion (fearful/happy/neutral), block (four levels), and trial number (12 levels) were included as fixed effects in our mixed models. To accurately investigate time-related changes while accounting for time-related confounds, we included the trial number as a discrete variable and we modeled autocorrelations between subsequent trial measurements by a first-order autoregressive covariance matrix. As suggested by Pinheiro and Bates (2000), we assessed the significance of terms in the fixed effects by conditional *F*-tests and then report *F* and *p* values of the Type III Sum of Squares

computations. Here, we decided to report the degrees of freedom of our comparisons, but note that the calculations of those relevant denominator degrees in mixed-effects models are approximations. All pair-wise comparisons were Bonferroni corrected. The normality and homogeneity assumption for the linear mixed-effects models was assessed by examination of the distribution of residuals.

Two sets of analyses were carried out. Firstly, a global analysis included all experimental variables and was aimed at exploring the overall patterns of ANS sensitivity of the participant groups to the various experimental conditions. Secondly, an additional, more focused analysis addressed autonomic responses specifically to emotional faces as canonical social stimuli. The choice of adding in-depth analyses of social stimuli was guided by the relevance of faces to the cognitive-behavioral manifestation of both of the clinical syndromes we focused on, as outlined in the introduction. Moreover, face stimuli have been shown to elicit atypical patterns of neural activity in individuals with both syndromes (e.g., WS: Haas and Reiss 2012; Haas et al. 2009; ASD: Dalton et al. 2005).

Global ANS Analyses: Drawing the Broad Picture

The global model applied to EDA data indicated that groups differed significantly in their overall EDA reactivity ($F(2, 42) = 7.127, p = 0.002$), and pair-wise comparisons highlighted that children with ASD showed less pronounced decreases of EDA as compared to TD participants in response to stimuli overall ($M_{ASD} = -0.31, M_{TD} = -0.49, p = 0.003$) (see Fig. 3a). The analysis further revealed significant interaction effects between group and block ($F(6, 2035) = 3.34, p = 0.003$), and group and emotion ($F(4, 2035) = 3.17, p = 0.013$). Specifically, TD and ASD groups showed a similar pattern of ANS modulation over time, associated with diminished arousal, with children with ASD demonstrating a slightly more gradual change (see Fig. 3b for results concerning pairwise comparisons). While children with WS tended to demonstrate the opposite pattern, pair-wise comparisons failed to yield significant differences, which may stem from high variability in the data and/or a lack of statistical power due to the small sample size. With respect to the group by emotion interaction, children with WS showed significantly higher relative levels of arousal as compared to TD participants in response to happy stimuli ($p < .05$). In addition, children with ASD showed increased arousal as compared to TD participants in response to neutral and happy stimuli (see Fig. 3c for results concerning pair-wise comparisons). There were no other statistically significant differences.

Secondary ANS Analyses: Focus on Social Stimuli

The focused model applied to EDA data revealed a significant main effect of group ($F(2, 42) = 7.17, p = 0.002$), with participants with ASD showing higher arousal, relative to TD participants, in response to faces ($M_{ASD} = -0.27, M_{TD} = -0.50, p = 0.004$), regardless of their affective valence (see Fig. 4a). Experimental groups were also associated with specific differences in ANS responsivity between stimulus blocks ($F(6, 1003) = 3.12, p = 0.005$). While the TD and ASD groups demonstrated similar trends associated with diminishing arousal over time (albeit less steep pattern for the ASD group), this was in sharp contrast to the pattern for children with WS (see Fig. 4b). There was also a significant group by emotion interaction ($F(4, 1003) = 3.17, p = 0.013$). While pairwise comparisons failed to

highlight statistically significant differences for the WS group, the ASD group showed higher arousal relative to the TD group specifically in response to happy and neutral faces (see Fig. 4c).

In order to examine the group-specific ANS sensitivity patterns to faces in depth, we also explored the statistically significant three-way interaction of group by emotion by trial ($F(4, 1003) = 3.455, p = 0.008$). Figure 5a, b, and c depict, respectively, the EDA event-related change scores over time with respect to trials representing fearful, happy, and neutral faces. Dotted lines represent the estimated polynomial trend-lines for each experimental group, which are used to illustrate more clearly non-linear tendencies in time-series data. As displayed in Fig. 5a, children with ASD and TD tended to show rather constant sympathetic responses to fearful faces. By contrast, children with WS showed initially diminished arousal to fearful faces, which then accelerated to the levels associated with the children with ASD and TD. Reactivity to happy faces varied considerably across groups (Fig. 5b): EDA reactivity for TD and ASD groups tended to vary little and show slow decreases over time, while children with WS were associated with a variable, sinusoidal pattern characterized by larger event-related changes (both increases and decreases in arousal) over time. Finally, concerning neutral faces (Fig. 5c), we observed greater variations over time in the WS group as compared to the TD and ASD groups, who tended to show constant and slowly decreasing ANS responses. However, in contrast to the pattern observed for trials of happy faces, the range of EDA measures for the WS group did not change with subsequent trials. The analyses of other ANS measurements did not reveal any statistically significant differences.

SRS

Mean T-scores and SDs for each subscale for children with WS, ASD, and TD are displayed in Table 2. Figures 6 and 7 illustrate the number of children with WS and ASD, respectively, with T-scores falling within the different classifications across the six domains of social functioning (including the total score). A one-way ANOVA conducted for the data from children with WS and ASD indicated that the only domain of social functioning that discriminated between the clinical groups was Social motivation ($F(1, 27) = 9.22, p = .005, \eta^2 = 0.25$), with children with WS demonstrating less impaired behavior. All other subscales failed to yield significant between-group differences (all p values $> .10, \eta^2$'s < 0.10).

Relations Between ANS Functioning and SRS

In order to specifically elucidate potential associations between autonomic activity in response to social stimuli and social functioning in children as sources of heterogeneity observed in these domains, Pearson correlations (two-tailed) were applied between event-related EDA change scores in response to face stimuli and the SRS data. These analyses were thus in line with the focused analyses applied to the ANS data. For children with WS, more typical (i.e., lower) Social Motivation score on the SRS was associated with a higher EDA response to fearful ($r(11) = -.63, p = .039$) and neutral ($r(11) = -.88, p < .001$) faces. For children with ASD, more typical score on the SRS Social Awareness subscale was associated with a lower EDA response to neutral faces ($r(17) = .50, p = .043$). For TD children, lower score on SRS Social Motivation subscale was associated with a smaller EDA

response to happy ($r(20) = .53, p = .016$) and neutral ($r(20) = .48, p = .032$) faces. All other correlations failed to reach significance.

Relations Between Social Perceptual Ability and SRS

Finally, Pearson correlations (two-tailed) were performed on emotion identification scores within the social domain and SRS data in order to elucidate how social perceptual ability may be linked to social functioning in the experimental groups. The results indicated significant associations only for children with WS: higher ability to identify happy facial expressions ($r(12) = -.71, p = .009$) was associated with lower scores on the Social Awareness subscale, reflecting more normal functioning. In addition, greater performance with identifying neutral stimuli was associated with higher total SRS scores ($r(12) = .65, p = .022$). All other correlations failed to reach significance.

Discussion

The present study addressed emotion identification ability and social functioning as measured by the SRS in conjunction with ANS responsivity patterns to affective stimuli in CA-matched groups of children with WS, ASD, and TD. Previous studies investigating social functioning and social reciprocity employing the SRS (Klein-Tasman et al. 2011; van der Fluit et al. 2012; Riby et al. 2014) have been within-WS investigations. Thus, the current study comparing age-equivalent samples of children with WS and ASD contrasted with TD not only provides novel insight into the syndrome-specific and syndrome-general features related to social skills in children at the equivalent developmental stage, but by linking autonomic activity to social and emotional functions begins to sketch a deeper characterization of the respective social profiles than those available previously.

Results from the emotion identification portion indicated that, after controlling for IQ differences between groups, children with WS uniquely exhibited deficits in identifying neutral emotion that were evident in relation to both ASD and TD groups, which performed similarly. There were no condition specific effects, suggesting that basic emotion perception judgments of children do not discriminate between social/facial versus non-social/object and scene stimuli. While altered fear perception and associated neural activity has emerged as a defining feature of WS (e.g., Meyer-Lindenberg et al. 2005; Thornton-Wells et al. 2011), it is interesting to note that children with WS in the current study showed no such deficits after between-group differences in IQ were controlled for. Finally, in the introduction it was noted that individuals with ASD have been documented to demonstrate highly heterogeneous affect processing abilities. On the basis of the current small-scale study focusing exclusively on children, both WS and ASD populations appeared to exhibit roughly similar levels of within-group variability.

Results from the SRS were largely in line with previous studies (Klein-Tasman et al. 2011; van der Fluit et al. 2012; Riby et al. 2014) highlighting that whereas children with WS tend to exhibit relatively unimpaired social motivation, they demonstrate pronounced deficits in social cognitive domains (see also Tager-Flusberg and Sullivan 2000). Children with WS and ASD largely displayed a similar overall degree of social dysfunction; however, whereas those with ASD tended to show rather uniform patterns of impairment across the targeted

social domains, children with WS exhibit a more variable pattern (cf. Klein-Tasman et al. 2011).

Correlational analysis between facial expression identification scores and SRS data provided insight into the contribution of social perceptual ability to parental reports of real life social functioning particularly in WS. Specifically, for children with WS, higher performance in identifying happy, and lower skill in identifying neutral facial expression, was specifically linked to more normal social functioning, highlighting the special status that perception of happy (cf. e.g., Dodd and Porter 2010) and neutral stimuli may play in the social profile of such individuals. As neutral faces were most commonly misidentified as fearful by individuals with WS, it may be those who are “hyper-vigilant” to fearful emotion that show the most normal social functioning in real life. The current pattern of results may further imply that the children with WS with more normal social function are specifically emotionally tuned and aware. Moreover, as discussed below, it is interesting to note that participants with WS did not differ from the ASD and TD groups in their psychophysiological response for neutral stimuli. Finally, the current results for the WS group are consistent with those reported by van der Fluit et al. (2012), who observed a significant correlation between an increased ability to interpret ambiguous social dynamics and fewer parent-reported social reciprocity difficulties in real life in WS. It thus appears that as suggested by an initial study by Jarvinen-Pasley et al. (2010), compromised emotion perception indeed contributes to the broader abnormalities in real-life social interactive behavior in WS linked to social reciprocity, communication, and motivation. The current findings should however be considered with caution due to the small sample sizes and high levels of behavioral emotion identification in the ASD and TD groups, which may have affected the correlational results. While we attempted to control for Type I error by limiting the correlational analyses within the social domain, caution should be exercised when interpreting the results due to the relatively high number of contrasts run.

Interesting between-group differences in ANS reactivity as indexed by EDA were found. It is noteworthy here that we opted for a trial focused data analysis approach due to the fact that EDA tends to show a slowly progressive decreasing latent trend during long recordings. Event-related relative changes, in effect, may thus act as fine-grained markers of relevant sympathetic responses, and smaller negative changes, compared to larger stimulus-related decreases in EDA levels, which may mirror relatively higher activation of sympathetic autonomic branch.

Most notably, children with ASD demonstrated higher overall arousal as compared to TD children, while those with WS and TD were associated with indistinguishable overall arousal levels. This pattern is slightly different to that reported by Riby et al. (2012) although on the basis of their study, direct comparison of WS and ASD individuals is not possible. In their study, those with TD showed higher SCL than individuals with WS, and individuals with ASD demonstrated higher SCL than their TD counterparts. While previous studies have distinguished subgroups in ASD on the basis of baseline SCL (Hirstein et al. 2001; Mathersul et al. 2013; Schoen et al. 2008), in the current study, significantly lower EDA decreases, and thus relatively higher arousal in response to all stimuli regardless of affective and social valence was found for children with ASD as compared to TD children.

By contrast, those with WS showed more variable reactions with no significantly different overall patterns of reactivity as compared to both the TD and ASD groups. The overall modulation of ANS changes over time was similar in children with ASD and TD, characterized by a pattern of gradually diminishing arousal with increased exposure to stimuli, or habituation. The variable, non-habituating pattern of ANS function in individuals with WS may potentially mirror some of the social as well as pathological features of their profile, which are currently poorly understood. The more “positive” aspects may include increased interest in face stimuli and heightened approachability toward unfamiliar people, as face stimuli may appear unusually novel to them despite repeated exposure, due to lack of habituation (cf. Jarvinen et al. 2012). Additionally, the present findings highlighted a lack of familiarity with stimuli in the non-social domain. As WS is specifically associated with anxiety that is predominately non-social in nature (e.g., Leyfer et al. 2006), this ANS feature may also contribute to some maladaptive features of the syndrome. Thus, a similar mechanism involving a lack of habituation to stimuli may also underpin a host of maladaptive behaviors, including attentional problems, restlessness, phobia, tension, and diagnostically significant anxiety (e.g., Dykens 2003; Leyfer et al. 2006). In the case of phobic behaviors, which are frequently diagnosed in individuals with WS, the lack of ANS habituation to the target stimuli may keep the phobia active and thus resistant to treatment. Of interest here are the findings of a recent study by Riby et al. (2014), which examined linkages between the level of social functioning (the SRS) and anxiety in individuals with WS. Individuals identified as low-anxious exhibited significantly more normal social awareness, social communication, and social cognition as compared to their high-anxious counterparts. Indeed, current results suggested a link between more normal social functioning and higher social perceptual awareness/vigilance in individuals with WS. Further large-scale studies are needed to clarify the link between autonomic reactivity in individuals with WS and their psychopathology, including that related to social functioning, abnormal processing of fear/threat, and anxiety.

With respect to emotion-specific effects, children with WS showed higher arousal relative to TD children in response to happy stimuli, while a similar effect was observed for children with ASD with the neutral stimuli. The finding of increased arousal in response to happy images in children with WS is consistent with previous behavioral reports of “positive affective bias” in WS (Dodd and Porter 2010) as well as with combined ERP and fMRI evidence that highlights significantly increased neural activity in individuals with WS relative to TD controls to happy faces (Haas et al. 2009). For children with ASD, however, patterns of ANS reactivity across the individual affect categories were indistinguishable, whereas those with WS and TD displayed responses that mirrored the common arousability characteristics of the stimuli (highest arousal to fearful faces and lowest arousal to neutral faces). This finding may reflect an ANS correlate of the impairment in emotional reciprocity that is a core feature of ASD (APA 2000).

Given that both WS and ASD are associated with atypical social behavior, focused analyses were justified within the social domain. Children with ASD demonstrated increased overall arousal in response to social stimuli relative to TD children, as well as specifically to happy and neutral faces. Further, children with WS demonstrated a strikingly different pattern of ANS responsivity to fearful faces as compared to both ASD and TD groups, which reacted

similarly. Namely, the responsivity pattern of those with WS was characterized by initially diminished arousal to fearful faces relative to ASD and TD groups, but with time, it gradually accelerated to levels comparable to those associated with the other groups. This pattern might be linked to the reduced sensitivity to socially relevant fear and threat, and associated amygdala hypoactivation that has been reported for individuals with WS (Meyer-Lindenberg et al. 2005). The initial lack of arousal may thus correspond to neural hypoactivation, and potentially behavioral neglect of the stimuli. This interesting initial finding warrants further research with fine-grained analysis techniques of ANS measures into fear and threat perception in WS, which is a landmark characteristic of the syndrome. Finally, whereas the ASD and TD groups showed slow and stable patterns of ANS activity in response to happy face stimuli, responsivity pattern of those with WS was highly variable over time. Taken together, our findings of elevated overall arousal level together with augmented ANS reactivity to faces in children with ASD relative to TD controls are in line with several previous reports (Bal et al. 2010; Barry and James 1988; Hirstein et al. 2001; Kylliäinen and Hietanen 2006; Palkovitz and Weisenfeld 1980). However, all groups showed similar magnitude of ANS responsivity across the social and non-social conditions as the group by condition interaction failed to reach significance, mirroring the pattern observed in the behavioral domain. Thus, we failed to replicate previous findings of blunted ANS reactivity to faces in relation to non-social stimuli in individuals with ASD (Hirstein et al. 2001). As ANS function is notoriously heterogeneous in ASD (see e.g., Mathersul et al. 2013; Klein-Tasman et al. 2007), the inconsistencies between the current and previous findings between studies may reflect that. Moreover, as the majority of previous studies have tested older individuals than those included in the current study, discrepancies between findings may additionally reflect maturational differences (also at the level of neurobiology), as well as those pertaining to the study design and analysis techniques employed (cf. Mathersul et al. 2013; Järvinen and Bellugi 2013).

The current findings for the WS group of indistinguishable EDA to those with TD stand in contrast to previous EDA-based findings that suggest hypoarousal in such individuals (Doherty-Sneddon et al. 2009; Riby et al. 2012; Plesa Skwerer et al. 2009). The failure to detect such differences in the current study may reflect Type II error and/or a lack of power due to the smaller sample size of the WS group. However, the current findings showing similar overall level of responsivity to faces between children with WS and TD are in line with previous studies of EDA function in more mature individuals (Doherty-Sneddon et al. 2009; Riby et al. 2012). At the same time, this finding is inconsistent with our previous result of general acceleration in mean HR and decreased HR variability to faces, in adults with WS relative to TD, using the same paradigm (Järvinen et al. 2012). There are several possible explanations for this discrepancy. First, it may reflect a developmental effect, whereby the ANS overall reactivity and the influence of the vagal complex on the cardiovascular system become more stable and consistent over time in WS. Second, whereas the existing studies focused on EDA baseline levels, our analyses were conducted on event-related change scores indexing EDA reactivity.

Analyses of ANS data further elucidated the association between the sensitivity to socially relevant emotion and social functioning across groups. In line with our hypotheses, whereas for children with WS, higher EDA change scores indexing greater autonomic reactivity were

associated with more typical social functioning as indexed by the SRS, this pattern was reversed for both the ASD and TD groups, for whom higher EDA responses were related to poorer social function. It is important to note here, however, that all TD children scored within the normative range on the SRS. ANS responses linked to social functioning appeared to specifically pertain to responsivity to neutral emotion across groups, suggesting that autonomic sensitivity to non-emotional visual stimuli in general is important to social reciprocity.

Studies of ANS reactivity in TD children have indicated associations with temperament (Calkins 1997; Snidman et al. 1995; Stifler and Fox 1990), behavior problems (Porges et al. 1996), and intellectual function (Doussard-Roosevelt et al. 1997). More specifically, higher levels of baseline skin conductance function have been associated with behavioral inhibition and shyness (Kagan et al. 1988; Scarpa et al. 1997), and children with emotional disorders demonstrate increased psychophysiological reactivity to unpleasant stimuli (Cole et al. 1996). While it is important to acknowledge that the EDA change scores examined in the present study relate to event-related autonomic responses and not to baseline autonomic function, it appears that the profile characterizing the TD and ASD children is consistent with the TD literature suggesting links between high autonomic function and psychopathology, while the opposite pattern appears to characterize the WS population. For example, in Mathersul et al.'s (2013) study, the participants with ASD who demonstrated abnormally low SCLs exhibited pronounced deficits in social skills, while those with more typical autonomic function showed relatively unimpaired social skills. As in the current study, children with ASD tended to display higher levels of arousal overall as compared to their TD counterparts, this may account for the fact that higher EDA change scores were associated with social dysfunction in the ASD (and TD) group.

In the current study, the ANS function of children with WS was rather heterogeneous, both *within* and between individuals, although the sample size was small. While it is difficult to determine whether the current heterogeneity was due to the small sample size, and/or the developmental status of the participants which may itself have been heterogeneous, in light of the heterogeneity reported in both the cognitive and social domains in WS (Porter and Coltheart 2005; Little et al. 2013), the variability in ANS function warrants further attention in future investigations. However, since the adults with WS in our previous study (Järvinen et al. 2012) exhibited less variability in autonomic reactivity than the children in the current study, this difference may at least partially reflect delayed maturation and consolidation of some autonomic responses in WS as compared to TD (and potentially ASD). It thus remains to be clarified in larger-scale investigations how aspects of autonomic function contribute to cognitive and social functioning across diverse domains in individuals with WS and ASD.

Study Limitations

The inclusion of static emotional stimuli likely contributed to the lack of between-group differences in emotion identification ability, as some stimulus classes may have appeared too easy for children with ASD and TD. While the use of dynamic stimuli may have uncovered more subtle profiles of ability and impairment across groups (e.g., Riby et al. 2012), as well as may have provided a more ecologically valid representation of socially relevant abilities

in real life, the operationalization of dynamic non-social stimuli is problematic. As such, the current, widely used standard stimuli are consistent with a large body of existing literature used to delineate, e.g., the neural correlates of emotion processing in both typical and atypical development (e.g., Hariri et al. 2002; Baumgartner et al. 2006; Cohen et al. 2013; Meyer-Lindenberg et al. 2005). This consistency enhances the ability to interpret the current results in the context of the broader picture. A related limitation concerns the fact that no eye tracker was used as an objective method to ensure that the children were properly attending to the visual stimuli during the passive portion of the experiment. However, the experimenter closely observed the children, and the participants were also videotaped, which enabled us to check the children's looking behavior subsequent to the testing session.

The sample sizes of the current study were small, particularly in terms of the WS population. As the current study specifically focused on children aged 13 years and younger, the small sample size of the WS group reflects the rarity of the condition and the difficulty of recruiting sizeable samples. At the same time, the current sample sizes are comparable to those in existing literature focusing on these populations.

The lack of an MA-matched control group for the WS group (and to a lesser extent, ASD sample) was overcome by controlling for IQ differences between groups. This was especially important as performance correlated with cognitive ability in the clinical groups. However, this statistical procedure may have introduced Type II error by removing some effects that may have been observed had a developmentally disabled comparison group been included in the study. Future larger-scale studies should therefore consider the limitations in the current research design to improve our understanding of the social-emotional profiles of individuals with WS and ASD.

Conclusions

The present study identified both syndrome-specific and syndrome-general features in profiles of emotion identification, autonomic reactivity, and social functioning in children with WS and ASD. Children with ASD exhibited higher levels of arousal than TD participants in response to face stimuli; however, these children also failed to show differential ANS sensitivity across fearful, happy, and neutral faces, unlike their counterparts with WS and TD. Thus, in some respects, these children exhibited blunted responsivity to emotions expressed by the faces, suggesting that it may be the face per se, and not the emotion, that is the source of arousal for such individuals. For children with WS, unique deficits in identifying neutral stimuli were found, which were linked to the level of social functioning, and variable modulation of EDA over time may represent an ANS correlate for specific positive social as well as for maladaptive features of the syndrome. While autonomic responsivity to neutral faces was associated with social functioning in all children, converging profiles of autonomic reactivity characterized children with WS contrasted with TD and ASD. The current study extends the existing literature by linking autonomic responsivity profiles to patterns of social functioning in children, and by indicating valence-specific response patterns for both WS and ASD relative to TD. The results raised a number of intriguing questions that remain to be addressed in future studies, which may have important implications for clinical interventions for individuals with WS

and ASD. For example, may training individuals with neurodevelopmental disorders on social skills, such as emotion perception, also affect their related physiological sensitivity over time?

Acknowledgments

This research was supported by NICHD 033113, NINDS 22343, and The Oak Tree Philanthropic Foundation to UB. We warmly thank all the participants, their families, and the Williams Syndrome Association for their generous cooperation in these studies. We also thank Patricia Fillet, Courtney Pollock, Wenny Wong, Nicholas Woo-VonHoogestyn, and Molly Hanson for their assistance in the data collection. Illustrations copyright Ursula Bellugi, The Salk Institute for Biological Studies, La Jolla, CA 92037-1002.

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Fig. 1.

Examples of test stimuli conveying fearful, happy, and neutral affect across the social and non-social conditions

Fig. 2.

Accuracy of visual emotion identification for children with WS, ASD, and TD, across the happy, fearful, and neutral categories for both social and non-social stimuli (*Error bars represent ± 1 SEM*)

Fig. 3.

a Illustrates that children with ASD demonstrate lower decreases of EDA relative to TD participants in response to stimuli overall. **b** Significant interaction effects between group and block, and between group and emotion. The TD and ASD groups showed a similar pattern of ANS sensitivity modulation over time, while children with WS tended to show the opposite pattern (*asterisks mark* pair-wise comparisons where $p < 0.05$, while pair-wise comparisons where $0.05 < p < 0.10$ are marked as *trends*). **c** Illustrates a group by emotion interaction, with WS group showing significantly higher relative levels of arousal than TD participants in response to happy stimuli, while participants with ASD showed more arousal

as compared to TD participants in response to neutral and happy stimuli (*asterisks mark* pair-wise comparisons where $p < 0.05$, while pairwise comparisons where $0.05 < p < 0.10$ are marked as *trends*)

Fig. 4.

a Illustrates a significant main effect for group, with participants with ASD showing higher arousal as compared to TD participants in response to faces overall. Experimental groups also exhibited differential responsivity across recording blocks. **b** Unlike those with WS, participants with TD and ASD showed similar trends of decreasing arousal in the social condition (*asterisks* denote pairwise comparisons where $p < 0.05$). **c** Illustrates a group by emotion interaction: the ASD group was associated with higher arousal relative to the TD

group in response to both happy and neutral faces (*asterisks* denote pair-wise comparisons where $p < 0.05$, while pairwise comparisons where $0.05 < p < 0.10$ are marked as *trends*)

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Fig. 5.

EDA event-related change scores over time for the experimental groups with respect to trials presenting fearful, happy, and neutral faces. *Dotted lines* represent the estimated polynomial trend lines for each experimental group, which are used to describe and to sketch more clearly non-linear tendencies in time-series data. **a** Depicts EDA reactivity for fearful faces. **b** Depicts EDA reactivity for happy faces. **c** Depicts EDA reactivity for neutral faces

Fig. 6.
Percentage of children with WS falling in the average, mild-to-moderate, and severe ranges on the SRS parent report inventory (number of participants indicated)

Fig. 7.

Percentage of children with ASD falling in the average, mild-to-moderate, and severe ranges on the SRS parent report inventory (number of participants indicated)

Table 1

Mean characteristics of the participant groups (SD; range in italic)

	CA (SD; range)	VIQ (SD; range)	PIQ (SD; range)	FSIQ (SD; range)
WS (n = 12)	11.4 (1.4; 9.6–13.9)	74 (9.3; 59–84)	66 (7.1; 59–83)	68 (7.7; 55–78)
ASD (n = 17)	10.6 (1.8; 7.5–13.7)	101 (20.7; 72–138)	98 (15.8; 72–127)	99 (15.1; 78–128)
TD (n = 20)	10.7 (1.6; 7.5–13.0)	120 (10.3; 102–145)	108 (10.6; 93–129)	116 (10.4; 99–136)

Table 2

Mean SRS T-scores across participant groups

SRS domain	WS (n = 12)		ASD (n = 17)		TD (n = 20)	
	Mean	T-score (SD)	Mean	T-score (SD)	Mean	T-score (SD)
Social awareness	65.17	(11.1)	68.53	(9.8)	50.75	(8.4)
Social cognition	81.25	(6.8)	74.71	(11.7)	47.20	(6.5)
Social communication	74.00	(13.2)	75.60	(9.6)	47.25	(7.1)
Social motivation	58.08	(12.4)	72.00	(12.0)	48.70	(8.4)
Autistic mannerisms	88.92	(15.2)	83.71	(13.6)	48.05	(7.0)
Total score	77.50	(10.8)	79.88	(9.4)	47.75	(7.2)

Higher T-scores reflect greater deficits in the domain