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Autonomic responses to dynamic displays of facial expressions in adolescents and adults with Williams syndrome

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The behavioral phenotype characteristic of Williams syndrome (WS) is marked by strong interest in social interaction, manifested in attention to human faces, empathy, approach behavior and social disinhibition, often coexisting with generalized anxiety. Despite their heightened social interest, people with WS show deficits in explicit emotion recognition tasks similar to those of people with other developmental disabilities. In the current study we explored whether individuals with WS show distinctive autonomic responsiveness to social-emotional information, using skin conductance response and heart rate measures. Autonomic activation was investigated in response to facial expressions of emotion in adolescents and adults with WS, compared to age-matched normal controls and to age-, IQ- and language-matched individuals with learning or intellectual disabilities (LID). Overall participants with WS were less electrodermally responsive to dynamically presented face stimuli than the age- and IQ-matched LID group, and showed more heart rate deceleration when viewing emotional faces than the controls. These findings, indicating hypoarousal but increased interest in response to the dynamic presentation of facial emotions in WS, are consistent with the behavioral profile of high approachability toward social stimuli in this population.

Keywords: Williams syndrome; skin conductance response; heart rate; facial expressions; dynamic emotional displays

In the rapidly expanding field of social-affective neuroscience research, there has been a recent surge of interest in the use of psychophysiological measures to explore aspects of implicit processing of social and emotional information. Such measures potentially open a window onto different levels of neurobehavioral organization, as sensitivity to the emotional characteristics of various stimuli may be manifested in autonomic responses even when explicit recognition of the significance of an emotional expression is impaired or absent (Skuse *et al.*, 2005). Electrodermal activity or the changes in electrical conductance of the skin, and heart rate variability are widely used measures of autonomic nervous system activity that are integrated with emotional and cognitive states (Cacioppo *et al.*, 1993; Critchley, 2002).

Changes in electrical conductance of the skin indicating sympathetic arousal, have been tied to amygdala activation and the processing of emotionally salient cues (Dawson *et al.*, 2000), particularly in response to stimuli that signal threat or uncertainty (Boucsein, 1992), such as fearful faces (Williams *et al.*, 2001; Critchley *et al.*, 2002). Despite a relatively long history of use in experimental research, the psychological significance of electrodermal measures of arousal related to perceptual processing of emotionally laden stimuli remains somewhat controversial, due in part to inconsistent empirical findings: some investigators reported that differences in autonomic arousal as indexed by phasic skin conductance responses (SCRs) distinguished between types of emotionally salient sensory input (e.g. facial expressions of fear from neutral expressions; see Williams *et al.*, 2004), whereas others have not found emotion-specific autonomic response patterns (Cacioppo *et al.*, 1993; Lane *et al.*, 1999).

Changes in heart rate (HR) have also been shown to indicate autonomic responsiveness to processing of novel and/or affectively laden stimuli, since HR varies as a function of attentional states and emotion. One advantage of HR measures is that the direction of change (acceleration or deceleration in response to the perception of stimuli) is interpretable in terms of balance between sympathetic and parasympathetic nervous system activity: HR acceleration typically indicates sympathetic arousal, while deceleration indicates security with and/or interest in a stimulus. Thus, traditionally (Graham and Clifton, 1966) HR deceleration has been linked to attentional shifts (e.g. index of the orienting response) or an early pre-attentive process of stimulus registration (Binder *et al.*, 2005), whereas HR acceleration has been related to processing of aversive stimuli (e.g. index of the defensive response) or to anticipating a stimulus that requires cognitive elaboration (Lacey, 1967).

Processing of emotional stimuli by people with Williams syndrome (WS) is of particular interest for researchers in the

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area of affective and cognitive neuroscience because of the unique social phenotype associated with this neurodevelopmental disorder. WS is a genetically based neurodevelopmental disorder caused by a contiguous microdeletion of approximately 22 genes on chromosome 7 (7q11.23), including the gene encoding elastin (Korenberg *et al.*, 2000; Morris, 2006). An uneven cognitive profile, with relatively good language abilities and severe deficits in visuo-spatial construction skills is a hallmark of this syndrome (Mervis *et al.*, 2000). A distinctive feature of the behavioral phenotype characteristic of WS is a strong interest in social interaction, manifested in intense focused attention to human faces, high empathy toward people in distress, approach behavior and social disinhibition, often coexisting with high levels of generalized anxiety (Udwin and Yule, 1991; Klein-Tasman and Mervis, 2003; Tager-Flusberg and Plesa Skwerer, 2006). Face recognition skills are a relative strength in the context of severely impaired visuospatial-construction abilities (Bellugi *et al.*, 1994; Tager-Flusberg *et al.*, 2003). Despite a notable interest in the emotional states of other people, social judgments and interpretation of social cues are not always appropriate in people with WS (Laws and Bishop, 2004; Plesa Skwerer and Tager-Flusberg, 2006).

Bellugi and colleagues (1999) found that individuals with WS tend to give excessively positive ratings to faces in a test of approachability, a pattern of responding similar to that of amygdala damaged patients (Bellugi *et al.*, 1999). However, using a similar paradigm, Frigerio and colleagues (2006) found that people with WS gave unusually high positive approach ratings only for faces with happy expressions. These authors interpreted this response pattern as evidence that the tendency of people with WS to approach strangers indiscriminately should be explained not by an amygdala dysfunction, but by 'difficulty inhibiting their strong compulsion towards social interaction' (Frigerio *et al.*, 2006, p. 254), reflecting the special salience of social stimuli for individuals with WS. Porter and colleagues (2007) also collected social approach ratings and administered a battery of neuropsychological tasks tapping frontal lobe functioning, and explicit emotion recognition in WS. Their results suggested that performance on the social approach task was affected by impairments in emotion recognition abilities, which, in conjunction with impairments in response inhibition, was evidence for a frontal lobe dysfunction that could explain the hypersociability showed by people with WS.

Other studies using a variety of explicit emotion recognition tasks have also found no relative sparing in facial affect recognition in WS. Several research teams (e.g. Gagliardi *et al.*, 2003; Plesa Skwerer *et al.*, 2006a, 2006b) demonstrated that the ability to explicitly interpret the meaning of emotional facial or vocal expressions is impaired in WS, and no better than that of other people with intellectual disabilities matched on mental and chronological age. However, deficits in explicit emotion recognition do not preclude the possibility that people with WS might show a special sensitivity to others' emotional displays manifested in changes in autonomic responsiveness. Explicit recognition and labeling of emotional expressions are processes that engage prefrontal cortical systems and require cognitive-linguistic processing of the perceptual information, whereas autonomic responsiveness to emotionally salient stimuli is more directly related to amygdala activation that modulates, through its complex connections to other social-affective and attentional brain circuitry, the cortical processing of stimuli according to their affective salience (Zald, 2003).

Meyer-Lindenberg and colleagues (2005) examined the neural basis of the unique profile of social cognition in adults with WS compared to matched normal controls using fMRI, focusing on the regulatory interactions between prefrontal cortex and amygdala. When presented with threatening and fearful scenes without socially relevant content, amygdala activation in WS was abnormally increased. In contrast, amygdala activation was reduced when WS participants viewed angry and fearful facial expressions, socially relevant stimuli expressing threat, which reliably engaged amygdala in normal controls. Path analyses of the activation patterns in the two groups showed altered amygdala-prefrontal connectivity in WS. This study was the first to address the neural basis of emotional processing in WS, suggesting that abnormalities in the regulatory interactions between the prefrontal cortex and the amygdala may explain the pattern of decreased social fear and increased non-social fear reported in people with WS. But, as these authors point out, more research using other emotional stimuli is needed to further elucidate the specificity of social-emotional processing in WS and its link to possible genetically based neural abnormalities.

Given that SCRs and HR are amygdala-mediated measures of autonomic responsiveness (LeDoux, 2000; Adolphs, 2001), we used these two types of psychophysiological indices to explore whether the profile of heightened social interest and anxiety might be distinctly expressed at the autonomic level in WS. We investigated autonomic activation in response to facial expressions of emotion in adolescents and adults with WS, compared to age-matched normal controls (NC) and to age-, IQ- and language-matched individuals with learning or intellectual disabilities (LID). Unusual autonomic responses to stimuli have been found in several clinical populations, including those with genetically based neurodevelopmental disorders such as Down syndrome and Fragile X. With the exception of autism and Fragile X, the prevalent pattern among clinical groups is *hyporesponsiveness*, a decrease in amplitude of SCRs when compared to normal control groups (Stevens and Gruzelier, 1984; Martinez-Selva *et al.*, 1995; Miller *et al.*, 1999). Therefore, in addition to typical adolescents and adults, we also included a group of matched individuals with LID of mixed etiologies but excluding autism and Fragile X to serve as controls for the WS group.

Two competing hypotheses regarding autonomic responses (SCR and HR) to viewing dynamic displays of emotional faces were formulated, based on the specific

profile of heightened social-affective interest of people with WS: (i) Because of their strong interest in faces, especially those displaying emotion, individuals with WS would show increased arousal, manifested in increased SCR frequency and response amplitude, and accelerated HR when viewing dynamic stimuli of facial emotional expressions, compared to age and IQ-matched controls. (ii) Alternatively, because electrodermal activity typically reflects processing of threat or uncertainty-related information, the participants with WS will show fewer SCRs, with lower response amplitude. Further, they will show decreased HR, in a pattern of hypoarousal to the presentation of faces, which are interpreted as highly approachable social stimuli that elicit increased interest.

METHOD

Participants

Participants included 29 adolescents and young adults diagnosed with WS (13;1–32;1 years, M = 19;1, s.d. = 5;6, 19 females), 22 age-matched normal control individuals (12;8–27;3 years; M = 20;4, s.d. = 4;6, 11 females) and 28 age- and IQ-matched individuals with learning and intellectual disability of mixed or unknown etiology (13;9–23;1 years, M = 18;3, s.d. = 2;6, 19 females). All participants with WS had the 7q11.23 deletion confirmed by FISH test. The LID participants were screened for autistic traits using the Social Responsiveness Scale (Constantino, 2004) and only those scoring below the cut-off for autism spectrum disorders were included. Individuals with Fragile X syndrome were excluded from the LID group.

Participants were administered standardized measures of language, (PPVT-III; Dunn & Dunn, 1997) and IQ (KBIT, Kaufman & Kaufman, 1990) as part of a larger testing battery. The three groups were not significantly different on age, $F(2, 77) = 2.21$, $P = 0.12$ and the WS and LID groups were well-matched on IQ, $t(55) = 0.24$, $P = 0.81$ and on language scores, $t(55) = 0.62$, $P = 0.54$. Table 1 provides descriptive information for the participants in this study.

Experimental stimuli

The stimuli included short dynamic video clips of actors portraying specific emotions that were selected from the Mind Reading software (Baron-Cohen, 2002), a collection of images and video clips developed to train people with autism or other disorders to recognize expressions of emotion. For this study we chose videos in which the face of an actor was shown in frontal view, portraying an emotional expression for 5 s, with a progressive increase in the intensity of the emotion. To select the dynamic stimuli to be included in the experiment we instructed 23 normal adult volunteers to rate the video-clips on how natural the actor's portrayal of emotion looked and on the intensity of emotion displayed (1 = the least strong/least natural to 5 = the strongest/most natural). The volunteers rated seven or eight examples for each of the seven facial expressions (happy, sad, fearful, angry, disgusted, surprised emotions and neutral) portrayed by men and women in the video-clips. The raters were also asked to choose the three video clips for each expression in each gender group that they considered best exemplified the target expression. Based on these ratings, 42 video clips (21 males and 21 females portraying the six emotions and neutral expressions) were chosen for inclusion in the experiment.

These 42 facial expression video-clips were grouped into three brief movies, with 14 video clips per movie. The emotional face stimuli presented included two examples, in each of the three blocks, of anger, disgust, fear, happiness, sadness, surprise and a neutral expression, portrayed by an equal number of males and females. Each movie was 5 min long, consisting of alternating facial expression video clips, each approximately 5 s long and 1 of 3 neutral nature scenes randomly distributed, each approximately 10 s long, with a 1 s blank screen between each video clip. The nature scenes were included to allow the participants time for their autonomic system to return to baseline after potentially responding to the dynamic displays of facial emotional expressions and were thus considered to be part of the inter-stimulus interval (ISI). These nature scenes were taken from internet sources and displayed three views of an ocean shore washed by relatively calm waves. They were chosen to be emotionally neutral and to show an unchanging landscape presented in a dynamic display, consistent with the stimuli of interest: the dynamic portrayal of facial expressions.

Procedures

Participants were tested individually in a quiet room. They passively viewed the three brief movies while seated in front of an IBM ThinkPad computer with a 9×12 inch screen, placed on a table about 18 inches in front of them. They were instructed to try to relax and remain as still as possible throughout the movie presentation but to watch carefully the different movie clips, without further explicit tasks.

Table 1 Participant characteristics

	Williams syndrome			Learning/intellectual disability			Normal control		
	Mean	s.d.	Range	Mean	s.d.	Range	Mean	s.d.	Range
Age	19.1	5.6	13.1–32.1	18.3	2.6	13.9–23.1	20.4	4.6	12.8–27.3
IQ (K-BIT)	68.1	12.8	45–94	68.8	12.2	52–93	100.4	17.7	76–141
Language (PPVT-III)	79.8	8.7	62–103	81.4	10.2	54–96	105.8	20.2	82–141

At least 2 min prior to the presentation of the movies data collection was started to obtain a measure of the participants' baseline skin conductance level (SCL). The first two-movies included three pretrial stimuli at the beginning to allow the participant to become accustomed to the face video clips and avoid possible reactions due to novelty, while the third movie had a single pretrial display. The pretrial stimuli consisted of neutral-expression face video-clips and were not included in the data analyses. Movies were counterbalanced in presentation with the shorter pretrial display always placed third in the order. The order of presentation of the three movies was counterbalanced across participants.

After the psychophysiological data collection was completed, participants were shown 28 of the face stimuli (including examples of all types of expressions seen in the original movies) and they were asked to label the emotion portrayed by the person in the image. A list of common emotion terms (e.g. angry, mad, depressed, sad, joyful, happy, surprised, etc.) was available for consultation during the presentation of the stimuli. Participants responded verbally and answers were recorded verbatim (more complete information about this portion of the experiment can be found in Plesa Skwerer *et al*., 2006b). We include these behavioral data here only for the participants who also provided psychophysiological data, with the aim of directly comparing autonomic responsiveness and emotion recognition accuracy in the same sample. The entire procedure for each participant took approximately 25 min to complete.

Physiological measures

Skin conductance responses were collected using two Ag–Ag/Cl electrodes, approximately 0.25 inch in diameter. Electrodes were filled with a biopotential contact medium and placed on the palmar surface of the medial phalanges of the index and middle fingers of the non-dominant hand. A constant current of 0.5 V was applied through the electrodes to measure skin conductance. HR was collected using three pre-gelled foil electrodes placed on the back of the neck, the right shoulder and the left side of the abdomen. Recording was continuous throughout movie presentation and events were defined by audio tones, inaudible to the participant, sent to an audio tone detector, which incorporated event markers into data collection. All physiological equipment and the compact desktop computer used for collection and analysis were provided by the James Long Company.

Data analysis

Skin conductance data were analyzed using SCOR2, a software program that calculates event-related changes in SCR and reports the rise time, amplitude and recovery statistics, among others indices. The software was programmed to detect SCRs at a latency of 1 s after stimulus onset to 1 s after offset for each stimulus. SCRs were defined as increases in amplitude of at least 0.02 microsiemens occurring from 1 to 5 s after stimulus onset. The program also analyzed data after the response to confirm that recovery took place. To correct for individual differences in amplitude (due to testing environment, skin thickness, sweat gland density, etc.) all SCRs were divided by the participant's mean baseline SCL. This baseline SCL was obtained from the last minute of data collected at the end of the acclimation period, immediately prior to the onset of the first stimulus. This correction served to reduce error variance due to extraneous factors and increase power to detect differences in the psychological variables of interest (Dawson *et al*., 2000).

The participants' HR was sampled at one-second intervals throughout the experiment. Using the second by second data samples, the slope of the HR over time was calculated. This slope encompassed 5–6 points for the face stimuli, or 10–11 for the nature scenes (the ISI). Slope provided an indication of the degree of change across a trial and of the direction of HR change. We selected this measure of HR because it corrects for individual variation in HR due to age or body size variables.

RESULTS

Skin conductance

Mean response frequency and amplitude of SCRs were used as dependent variables in analyses of event-related electrodermal activity. Means were calculated for each type of facial expression (including six emotions and neutral expressions) and the data are presented in Table 2. Preliminary analyses of sex differences revealed no significant differences on any measures of electrodermal activity.

Table 2 Mean frequency and amplitudes of SCRs in each condition (s.d. in parentheses)

	Williams syndrome		Learning/intellectual disability		Normal control	
	Frequency	Amplitude	Frequency	Amplitude	Frequency	Amplitude
Angry	0.075 (0.14)	0.097 (0.21)	0.217 (0.27)	0.185 (0.15)	0.121 (0.17)	0.083 (0.08)
Fearful	0.106 (0.16)	0.060 (0.09)	0.179 (0.23)	0.155 (0.22)	0.136 (0.18)	0.077 (0.05)
Disgusted	0.124 (0.19)	0.067 (0.09)	0.202 (0.21)	0.146 (0.16)	0.068 (0.14)	0.058 (0.05)
Sad	0.129 (0.20)	0.032 (0.04)	0.185 (0.26)	0.109 (0.08)	0.121 (0.23)	0.102 (0.11)
Happy	0.147 (0.22)	0.061 (0.08)	0.185 (0.27)	0.194 (0.18)	0.152 (0.21)	0.206 (0.28)
Surprised	0.109 (0.19)	0.074 (0.10)	0.208 (0.23)	0.266 (0.39)	0.121 (0.17)	0.101 (0.08)
Neutral	0.101 (0.16)	0.057 (0.08)	0.181 (0.21)	0.148 (0.15)	0.099 (0.15)	0.096 (0.08)
Overall SCRs	0.113 (0.14)	0.061 (0.07)	0.194 (0.21)	0.148 (0.13)	0.117 (0.14)	0.089 (0.06)

Inspection of the distributions of the SCR data showed significant positive skew because the majority of participants did not show SCRs on a given trial. Logarithmic transformations applied to control for the effects of skew on SCR data (cf. Boucsein, 1992) did not improve the distributions sufficiently for parametric statistical analyses, therefore SCR frequency and amplitude data were analyzed non-parametrically.

Kruskal–Wallis ANOVA tests were conducted to evaluate group differences in the frequencies and the amplitudes of SCRs for each type of facial expression. To control for type I error (Bonferroni method), an alpha level of 0.016 was selected for significance. Kruskal–Wallis ANOVA tests did not reveal significant group differences for any emotion or for neutral expressions when frequency of SCRs was the dependent variable. For SCR amplitudes several significant group differences were found. Groups differed significantly in SCR amplitudes across all face stimuli, χ^2 (2, $N=65$) $=12.14$, $P=0.002$ and more specifically for the expressions *angry*, χ^2 (2, $N=42$) $=9.69$, $P=0.008$, *sad*, χ^2 (2, $N=39$) $=8.62$, $P=0.013$ and *neutral*, χ^2 (2, $N=38$) $=8.22$, $P=0.016$. Follow-up Mann–Whitney U-tests revealed that all these significant group differences were driven by the comparison between the WS and LID groups, with WS showing on average lower SCR amplitudes than the LID group for all faces, $z=-3.30$, $P=0.002$, for *angry*, $z=-2.77$, $P=0.006$, *sad*, $z=-2.72$, $P=0.007$ and *neutral* expressions, $z=-2.47$, $P=0.014$. The WS group also showed lower SCR amplitudes than the NC group for sad and neutral expressions (P-values <0.05) however the differences did not reach the conservative level of significance chosen ($P=0.016$). The LID and NC groups did not differ significantly in SCR amplitudes for any expressions. Wilcoxon tests were conducted within each group comparing SCR frequencies and amplitudes for each type of emotional expression versus neutral expressions. In all three groups SCRs failed to clearly differentiate between emotional and neutral facial expressions.

Heart rate

HR data from five participants (one NC, two WS and two LID) could not be processed due to technical difficulties. Preliminary analyses revealed no significant sex differences in HR data, however there was an expected significant correlation between baseline HR and participants' age, which can be accounted for by developmental differences in growth (shorter heart period in adolescents). Therefore, as noted, analyses were conducted on change scores (slope) rather than on raw HR data. These scores were normally distributed. Group means for each type of facial expression are presented in Figure 1.

One-way ANOVAs were conducted to compare HR slopes between groups and yielded significant group differences for mean HR slope across all emotional expressions, F (2, 73) $=9.36$, $P=0.001$, as well as for *angry*, F (2, 73) $=5.62$, $P=0.005$ and *surprised*, F (2, 73) $=3.35$, $P=0.02$ expressions. There were no significant group differences in HR slopes for neutral expressions. *Post hoc* Tukey HSD comparisons indicated that the participants with WS showed significantly greater HR deceleration than either the LID or NC group across all emotional expressions ($P<0.001$ for both comparisons). In addition, the WS participants had greater HR deceleration to *angry* ($P<0.01$) and to *surprised* faces ($P<0.05$) than did the LID group. No group differences in HR slopes were found between the LID and NC groups for any stimuli. These data suggest that the participants with WS show greater interest in the emotional face stimuli than either the NC or LID control group.

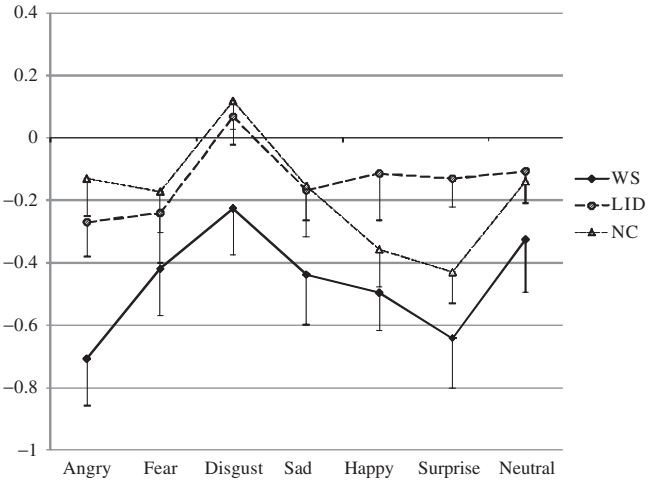

Fig. 1 Changes in heart rate as a function of stimulus type. Error bars represent the standard error of the mean (SEM). *$P<0.05$. **$P<0.01$. **Angry—HR deceleration: WS > LID; WS > NC. *Surprise—HR deceleration: WS > LID.

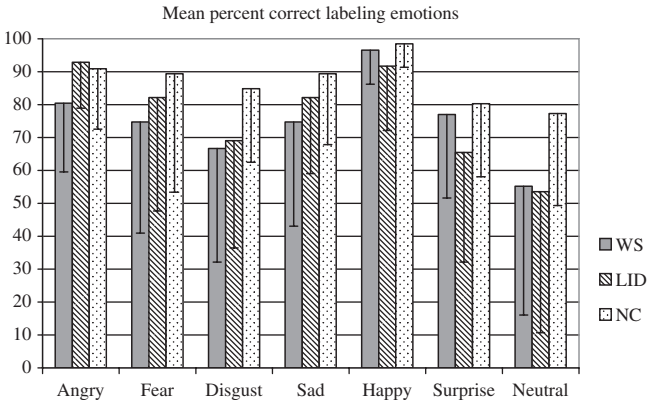

Fig. 2 Facial expression labeling accuracy by stimulus type.

Explicit emotion recognition

Figure 2 presents the percentage of correct labels by type of expression for each group. A one way ANOVA on labeling accuracy was significant, F (2, 78) $=11.02$, $P<0.001$ and follow-up *post hoc* Tukey HSD comparisons revealed that

the NC group was significantly more accurate than either the WS or the LID group ($P < 0.001$ for both comparisons) in labeling facial expressions, but that the WS and LID group did not differ from one another ($P = 0.87$). In all three groups the expression least well recognized was *fear* (*M* correct = 77.3% in the NC group, 40.2% in the WS group and 47.6% in the LID group) and the easiest to label was *happy* (see also Plesa Skwerer *et al.*, 2006b). There were no significant correlations between physiological measures of autonomic responsiveness and the labeling accuracy data for any of the groups, or between electrodermal and HR autonomic measures.

DISCUSSION

This study is the first to examine autonomic responsiveness to dynamic displays of facial expressions in people with WS, compared to age, IQ and language matched peers with other learning/intellectual disabilities and to age matched typical controls. The main findings were that, in comparison to the matched control groups, the WS participants showed reduced SCR amplitudes and greater HR deceleration across all facial expressions. Specific differences were found on the SCR measure to angry, sad and neutral faces, and on the HR measure to angry and surprised faces. In contrast to these significant differences on the autonomic measures, the WS group was no different than the LID group in their ability to label the facial expressions: both groups were impaired relative to the typical controls.

Overall, these findings support the second hypothesis, predicting that the WS group would show hypoarousal, as evidenced by reduced SCR amplitudes, and heightened interest, as evidenced by greater HR deceleration to the dynamic facial expressions. Thus, to the extent that SCRs are associated primarily with autonomically mediated defensive behaviors, such as increased vigilance in conditions of uncertainty, threat, potential danger, as possibly signaled by the display of negative emotional facial expressions, the diminished electrodermal responsiveness found in the individuals with WS suggests that they don't implicitly associate facial expressions to threat-related signals. Moreover, their differential HR deceleration to facial stimuli suggests the 'open attentional stance' usually associated with safety signals (Venables, 1991), indicating increased interest in people, not elevated attentional vigilance linked to aversive stimuli or defensive responding. At the same time, it is important to note that these unique autonomic responses are not related to explicit measures of social cognition (e.g. emotion labeling abilities).

The SCR findings are consistent with other data suggesting that people with WS do not find other people to be threatening. Thus, the data fit with anecdotal and parent report evidence that at all ages, people with WS are more likely to approach strangers (e.g. Gosch & Pankau, 1997; Dykens & Rosner, 1999;) and with the sociability and trustworthiness data reported by Bellugi *et al.* (1999). The HR data are interpreted as measuring the increased interest toward social-affective stimuli in people with WS. This unusual interest in people begins during infancy, when babies with WS show more intense and focused attention toward other people's faces, especially strangers (Jones *et al.*, 2000; Mervis *et al.*, 2003). Attention to faces is associated with relatively spared face recognition skills (Bellugi *et al.*, 1994; Tager-Flusberg, *et al.*, 2003) and with greater sensitivity to unexpected changes to people in a change-blindness paradigm (Tager-Flusberg *et al.*, 2007). Given the distinctive pattern of findings reported here for the group of individuals with WS, this profile of autonomic responsiveness to social-affective stimuli may represent a unique feature of the social phenotype of WS.

In contrast to these differences on the autonomic measures of responsiveness to social-affective stimuli, the WS group was no different than matched LID comparison group on explicit measures of emotion recognition ability. Their heightened interest in emotionally expressive faces did not translate into the WS participants' ability to more accurately decode cues to distinguish between different emotions, especially negative emotions. Thus, emotion recognition accuracy was significantly lower in the WS and LID groups compared to that of age matched typical controls. These findings are consistent with several other studies using a variety of different types of facial expressions of emotion (Gagliardi *et al.*, 2003; Plesa Skwerer *et al.*, 2006a, 2006b; Porter *et al.*, 2007). Interestingly, both clinical groups had difficulties recognizing neutral expressions, showing a tendency to attribute negatively valenced emotions to faces lacking clear cues to any expression of affect, which may explain why neutral expressions elicited SCRs (Davidson, 2003).

These findings suggest dissociation between implicit, autonomic measures of social-affective responsiveness and explicit measures of affect recognition. The implicit measures may not only provide a novel measure of the specific WS social phenotype, but may also offer a unique approach to investigating the neural substrates that underlie this aspect of the phenotype. Although autonomic measures are not direct assessments of brain structure or function, reductions in electrodermal activity have been associated with abnormalities in both limbic structures, including the amygdala, and in neural circuitry involving prefrontal and parietal cortices (Critchley, 2002). Thus, given the mediating role of the amygdala in activation of the autonomic nervous system (Davidson & Irwin, 1999), the finding of differential autonomic responsiveness in WS supports the hypothesis of possible amygdala dysregulation or of abnormal amygdala connectivity with other brain regions involved in social-emotional information processing (e.g. orbitofrontal, medial prefrontal areas). This would be consistent with the findings reported by Meyer-Lindenberg *et al.* (2005) who found lack of amygdala-prefrontal connectivity in WS using fMRI. Alternatively, our findings may reflect abnormalities in parietal cortex or frontal-parietal connectivity

(e.g. Tranel & Damasio, 1994; Critchley *et al.*, 2000), which would fit with data reported by Reiss and his colleagues (e.g. Reiss *et al.*, 2004; Thompson *et al.*, 2005; Eckert *et al.*, 2006; Mobbs, *et al.*, 2007).

In this study we used a variety of emotional expressions as stimuli including both positive and negative emotions; however, the design may have lacked the power to detect distinctive emotion-related differences in autonomic responsiveness. Our study also included relatively small numbers of participants in each group, a particular concern given the wide variability in their responses on the autonomic measures. These limitations preclude the possibility of investigating HR variability or of revealing systematic relationships between our autonomic measures. Although significant group differences were found on certain facial expressions, it is not clear how best to interpret the specific pattern, which did not include fearful faces, as would be expected. Future studies focusing on specific contrasts (e.g. fear *vs* sad, disgust *vs* angry) might reveal more differentiated atypical patterns of implicit processing of affective information in WS, which could be more directly related to abnormalities in neural substrates. For example, exploring differences in autonomic arousal to fear might more directly implicate the role of the amygdala in mediating the SCR patterns found in the participants with WS and responses to disgust may highlight the potential role of the insula, which thus far has not been systematically investigated in neuroimaging studies of WS. It would also be important for future studies to include more direct measures of attention, such as eye-tracking patterns, which would highlight the relationship between unusual patterns of attention and interest in faces in this population (cf.Mills *et al.*, 2000; Mervis *et al.*, 2003).

WS is often presented as a model syndrome for investigating the relationship between specific genes, brain and behavior patterns (e.g. Bellugi *et al.*, 1999). In a recent paper, Young and colleagues (2007) demonstrated that disruption in the functioning of the Gtf2ird1 gene in mice (which is related to a set of genes that are within the standard WS deletion span) led to an unusual social phenotype including decreased fear and aggression and increased social activity (Young *et al.*, 2007). This phenotype is strikingly similar to the phenotype for people with WS, as reflected in our findings from autonomic measures. The altered mice had increased levels of serotonin metabolites in several brain areas, including amygdala, frontal and parietal cortices and Young *et al.* (2007) suggest that the changes in the phenotype in these mice might be the result of alterations in the seratonergic modulation of the amygdala-prefrontal neural pathway. It would be interesting to incorporate evaluation of autonomic arousal in future studies of these altered mice to investigate whether they show the same altered pattern of response to social stimuli.

The use of psychophysiological measures of autonomic arousal in WS provides an indirect but informative avenue for further investigating how individuals with this neurodevelopmental disorder and unusual social phenotype process social-affective information at different levels of neurobehavioral organization. These measures may be especially useful when more direct investigations of brain activity using fMRI or other functional brain paradigms are difficult to conduct with such a rare population who shows a high degree of generalized anxiety. Such measures, in conjunction with methods that capture attentional deployment processes (e.g. eye-tracking), which might also be unique in WS (cf. Tager-Flusberg *et al.*, 2007), may contribute to advancing our understanding of the unusual social phenotype of people with WS and bring new insights into the neurocognitive mechanisms of social-emotional functioning in typical development.

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