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Electrodermal and Behavioral Responses of Children With Autism Spectrum Disorders to Sensory and Repetitive Stimuli

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Parents frequently report that their children with autism spectrum disorders (ASD) respond atypically to sensory stimuli. Repetitive behaviors are also part of the ASD behavioral profile. Abnormal physiological arousal may underlie both of these symptoms. Electrodermal activity (EDA) is an index of sympathetic nervous system arousal. The goals of this study were twofold: (1) to pilot methods for collecting EDA data in young children and (2) to examine hypothesized relationships among EDA, and sensory symptoms and repetitive behaviors in children with ASD as compared with children with typical development. EDA was recorded on 54 young children with ASD and on 33 children with typical development (TD) during a protocol that included baseline, exposure to sensory and repetitive stimuli, and play. Parents completed standardized questionnaires regarding their child's sensory symptoms and repetitive behaviors. Frequency and type of repetitive behavior during play was coded offline. Comparisons between EDA data for ASD and TD groups indicated no significant between-group differences in any measures. Parents of children with ASD reported more abnormal responses to sensory stimuli and more repetitive behaviors, but scores on these measures were not significantly correlated with EDA or with frequency of observed repetitive behaviors. Parent report of frequency and severity of sensory symptoms was significantly correlated with reports of repetitive behaviors in both groups. Although parents of children with ASD report high levels of sensory symptoms and repetitive behaviors, these differences are not related to measured EDA arousal or reactivity. *Autism Res* 2014, 7: 468–480. © 2014 International Society for Autism Research, Wiley Periodicals, Inc.

Keywords: autism spectrum disorder; psychophysiology; sensory; repetitive behaviors

Introduction

Autism spectrum disorder (ASD) is a neurodevelopmental disorder defined by deficits in social communication combined with a repetitive and restricted behavior repertoire, including abnormal behavioral reactions to sensory stimuli. Both sensory and repetitive symptoms were described in the very first account of ASD [Kanner, 1943]. Sensory symptoms and repetitive behaviors are included in diagnostic algorithms of the Autism Diagnostic Observation Schedule-Second Edition [Lord et al., 2012] and the Autism Diagnostic Interview-Revised [ADI-R; Lord, Rutter, & Le Couteur, 1994], gold standard diagnostic tools. Sensory symptoms have also recently been added to the classification of ASD in the fifth edition of the Diagnostic and Statistical Manual [American Psychiatric Association, 2013]. Despite this recognition, sensory symptoms and repetitive behaviors in ASD have received less research attention than the social-communicative aspects of the disorder [Baranek, 2002]. Understanding sensory symptoms in ASD has been a challenge because of variable symptoms observed in ASD, the variety of

theories concerning sensory symptoms, and the many challenges involved in the direct measurement of sensory responsivity and processing. The difficulty of understanding sensory symptoms is furthered because the relationship between sensory symptoms and repetitive behaviors has yet to be fully clarified. Sensory symptoms and repetitive behaviors are considered conceptually separate; however, they often manifest as the same overt behavior (e.g. stereotypy in response to sensory stimuli). Because both sensory symptoms and repetitive behaviors manifest in the same way, they may also have similar underlying mechanisms, specifically, atypical patterns of tonic or phasic arousal.

Sensory symptoms are defined as unusual behavioral reactions to sensory stimuli. Sensory symptoms are often described in three different patterns: sensory hyperresponsivity, sensory hyporesponsivity, and sensory seeking/craving [Miller, Anzalone, Lane, Cermack, & Osten, 2007]. Hyperresponsivity is characterized by extreme, rapid, and prolonged response to sensory stimuli. Hyporesponsivity is characterized by less intense or slower response to sensory stimuli. The

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sensory-seeking profile is described as craving an unusual amount of intense sensory experience.

As with atypical responses to sensations, repetitive behaviors manifest in a variety of patterns. Common patterns of repetitive behavior include motor stereotypies, highly focused special interests, echolalia, repetitive acts, rituals, and insistence on sameness [American Psychiatric Association, 2013]. These patterns of behavior are more common and often more severe in people with ASD than in individuals with other types of developmental impairments [Bodfish, Symons, Parker, & Lewis, 2000].

Multiple hypotheses have been offered to explain sensory symptoms in ASD and to link them to other ASD symptoms such as repetitive behaviors [see Rogers & Ozonoff, 2005 for a review]. There is currently, however, no integrated, empirically supported model that explains atypical sensory responsivity and repetitive behaviors in ASD. Two hypotheses propose that physiological arousal is a potential mechanism underlying sensory symptoms and repetitive behaviors.

One hypothesis suggests that heightened arousal and reactivity of the sympathetic nervous system (SNS) is responsible for both sensory symptoms and repetitive behaviors through the following mechanism: over-arousal prevents habituation to incoming sensory stimuli and thus causes sensory overload which manifests behaviorally in an extreme sensory reaction that requires the compensatory response of repetitive behavior [Dawson & Lewy, 1989; Hutt, Hutt, Lee, & Ounsted, 1964]. This hypothesis posits that engaging in repetitive motor behaviors serves to block additional sensory input and thus protects the individual from further over-arousal. The hypothesis also posits that insistence on sameness serves as a coping mechanism for a chronic state of over-arousal [Hutt & Hutt, 1965; Hutt et al., 1964].

An alternative hypothesis suggests that people with ASD have a general state of under-arousal of the SNS and diminished reactivity due to a lack of activation in the limbic system. The diminished reactivity manifests behaviorally as a lack of responsivity to sensory stimuli [DesLauries & Carlson, 1969; Rimland, 1964]. Consistent with this theory of sensory functioning, Lovaas, Newsom, and Hickman [1987] classified repetitive behaviors as self-stimulating and argued that motor actions normalize arousal levels and provide rewarding sensory input to individuals experiencing low arousal levels.

Research attempting to study sensory symptoms and repetitive behaviors must face the challenge of quantifying these symptoms. Quantification is difficult because these symptoms are rare in the lab. Researchers have most often turned to parent report to elicit a more representative picture of these behaviors in a person's repertoire [Rogers & Ozonoff, 2005]. A recent meta-analysis of studies using parent report measures identified 14 high-quality studies that included a specific measure of sensory

symptoms in both an ASD and a comparison group [Ben-Sasson et al., 2009]. Both the Rogers and Ozonoff [2005] review and the Ben-Sasson et al. [2009] meta-analysis found that the most commonly reported pattern of sensory symptom in these studies was hypo-responsivity rather than hyperresponsivity. However, all three patterns of sensory symptoms were reported by parents, sometimes within the same individual [Ben-Sasson et al., 2009; Boyd et al., 2010]. Parent report is commonly used largely because it is a relatively quick and economical method of collecting information and because it allows access to behaviors that can be infrequent or occur only in specific contexts. The problem with parent report is that parent questionnaire data involving a very well-known symptom can be subject to inherent response bias.

A second frequently used measurement approach involves behavioral observation of sensory symptoms and repetitive behaviors measured either directly or via video recordings. Findings from behavioral coding in retrospective video studies indicate that sensory symptoms emerge early in the development of ASD symptoms [Adrien et al., 1992, 1993; Baranek, 1999; Osterling & Dawson, 1994]. Sensory symptoms and repetitive behaviors have distinguished very young children with ASD from those with typical development. However, sensory symptoms and repetitive behaviors have not necessarily distinguished ASD from other developmental disabilities (DD) at early ages [Baranek, Boyd, Poe, David, & Watson, 2007; Watson et al., 2011]. Similar to findings from parent report studies, observational studies have found that the majority of children with ASD present with sensory symptoms that occur across response types and sensory domains [Baranek et al., 2007; Boyd et al., 2010; Watson et al., 2011]. Also similar to findings from parent report studies, an observational study identified hyporesponsiveness as a distinguishing characteristic of children with ASD, and demonstrated a positive relationship between hyporesponsiveness and social and communication symptoms [Watson et al., 2011].

A criticism of both behavioral observation and parent report methods is that overt behavior does not provide direct information about the processing of sensory information or about the physiological responses to sensory experiences. To examine underlying mechanisms, direct measures are needed.

Skin conductance, or electrodermal activity (EDA), has long been known to be a measure of SNS arousal. While not a direct measure of sensory processing, skin conductance is a reliable measure of arousal and reactivity. Previous studies used skin conductance to examine relationships between SNS arousal and sensory symptoms [Schoen, Miller, Brett-Green, & Nielsen, 2009; van Engeland, 1984]. Tonic measures of EDA are useful for testing general states of arousal over periods of time.

Phasic measures of EDA are useful for testing reactivity and habituation during short periods of exposure. Studies that have used EDA measures to study sensory responsiveness have reported mixed results. Some studies of phasic EDA measured during exposure to auditory probes found no differences in responses between children with ASD and those with either typical development or other clinical conditions [Schoen et al., 2009; Stevens & Gruzelier, 1984; van Engeland, 1984]. Only one study has reported ASD-specific differences in reactivity to auditory stimulation [Bernal & Miller, 1970]. The authors of this study found lower reactivity in their ASD group compared with typically developing comparison participants.

Findings involving olfactory, tactile, and novel visual probes indicate lower EDA reactivity in participants with ASD when compared with a group with sensory modulation disorder [Schoen et al., 2009]. Findings have been mixed when the comparison group involved participants with typical development [Schoen et al., 2009; van Engeland, Roelofs, Verbaten, & Slangen, 1991].

Findings of studies of tonic baseline measures of EDA are similar to the findings of phasic arousal. A comparison of tonic baseline measures of EDA found that a group of children with ASD demonstrated lower tonic arousal than either children with typical development or children with sensory modulation disorder [Schoen et al., 2009]. In spite of these findings, it has also been suggested that there may be patterns of both high and low tonic arousal in ASD [Hirstein, Iverson, & Ramachandran, 2001; Schoen, Miller, Brett-Green, & Hepburn, 2008]. Variability in findings could be due to age and functioning differences of the samples, to differences in type of stimuli and measures of physiology, or to the presence of multiple response patterns within ASD [Hirstein et al., 2001].

While direct measurements are important, multi-method approaches are necessary to examine relationships among physiological responses and infrequent sensory symptoms and repetitive behaviors. Combining methods helps to identify the limitations of each source of information. For example, a recent study compared heart rate responses of children with ASD to children with typical development during sensory exposure [Woodard et al., 2012]. Children in the ASD group revealed hyperresponsive heart rate responses to sensory stimuli compared with controls. In addition, heart rate responses were related to observed level of behavioral response but not to parent report of symptoms. In the study conducted by Schoen et al. [2009], both phasic and tonic measures of EDA demonstrated no relationship to parent report measures of sensory symptoms. A preliminary study examining heart rate in relation to self-injurious behavior found that the behavior may increase arousal [Lyndon, Healy, & Dwyer, 2013]. Thus, the use of physiological measures, such as EDA, with behavioral

measures is critical for examining the potential of physiological arousal as an underlying mechanism of sensory symptoms and repetitive behaviors.

Current studies of ASD only examine participants in later childhood through adulthood when using physiological measures. As reviewed above, sensory symptoms and repetitive behaviors are symptoms that occur early in the onset of ASD. To better understand the mechanisms underlying symptoms that occur early in the onset of the disorder, we must also examine participants as close to the onset of the disorder as possible. Consequently, methods need to be developed that can be used in the youngest children with ASD. A major goal of this study was to develop and test a method of collecting physiological data from young children with ASD.

Current Project

The aims of the current study were: (1) to pilot a procedure for examining EDA measures that could be used with very young children (age 2–4 years); (2) to compare phasic measures of EDA in response to various sensory and repetitive stimuli between children with ASD and with typical development; (3) to use a multi-method approach to examine relationships between EDA data and parent report of sensory symptoms and repetitive behaviors symptoms; and, (4) to test for relationships between tonic EDA and observed repetitive behaviors across play sessions with toys. We hypothesized that children with ASD would differ from children with typical development in their phasic EDA responses to sensory stimuli and to repetitive stimuli, and that the groups would differ in the relationship between phasic EDA data and data from parent report of sensory symptoms and repetitive behaviors (Fig. 1A). In addition, we hypothesized that tonic EDA would be related to amount of observed repetitive behaviors (Fig. 1B).

Methods

Participants

Participants were seen as part of the Autism Phenome Project (APP) at the University of California, Davis MIND Institute. Participants were recruited through the Subject Tracking System of the MIND Institute and through outreach efforts in the community including participation at events and mailing lists.

Fifty-four children (six female) with ASD between the ages of 29–56 months ($M = 39$, $SD = 6.6$) participated in the current study. All children had received a diagnosis of ASD in the community. The diagnosis was confirmed by a clinical psychologist using the ADI-R [Lord et al., 1994], the ADOS-G [Lord, Rutter, DiLavore, & Risi, 1999], DSM-IV criteria, and clinical judgment. To be

included in the study, the participant had to meet ADOS-G cut-off scores for either autism or ASD, had to meet ADI-R cut-off criterion on the social or communication subscale and be within two points of the cut-off on the other subscales, and had to meet clinical judgment for ASD. Participants with a history of significant motor delays or vision or hearing impairments were excluded from the study.

In addition to the 54 participants with ASD included in the final analyses, eight other participants with ASD were also seen; however, EDA data could not be collected for these participants. One participant had a birth defect that prevented the electrode placement. The other seven participants became too distressed either

during electrode placement or during the protocol. Thus, we were successful at gathering EDA data on 87% of participants with ASD in this young age group. The eight participants excluded did not differ significantly from the group included in these analyses on any of the behavioral measures including the parent questionnaires.

Thirty-three children (seven female) with typical development (TD) age 27–54 months ($M = 39$, $SD = 7.2$) also participated in this study. Typical development was confirmed using the Social Communication Questionnaire [SCQ; Rutter, Bailey, Lord, & Berument, 2003] and the Mullen Scales of Early Learning [MSEL; Mullen, 1995]. Excluded were children with scores in the range of concern on the SCQ (score > 11), children with scores greater than two standard deviations (SD) below the mean on any subscale of the MSEL, and children with a sibling with ASD. Participants with gross motor delays, hearing impairment, or vision impairment based on informal parent report were also excluded.

Table 1 presents participant characteristics. There was no significant difference between the ASD group and the TD group in chronological age ($t(1) = -.404$, $P = .68$), but there was a significant difference in mental age ($t(1) = -6.748$, $P < .01$). The ASD group had significantly lower mental age scores than the TD group.

General Procedures

This study was carried out under Institutional Review Board approval from the University of California, Davis. Consent forms were reviewed with each family, and all parent questions were answered before consent was obtained and before any measures were gathered. Measures were collected during multiple visits to the lab. During the first visit, qualifying behavioral measures were collected, and parents were instructed to complete questionnaire forms at home and return them at the next visit.

On the second visit, the children participated in the psychophysiological protocol. Electrode placement on the right foot began in the waiting area before entering the lab. In the waiting room, an experimenter spent time engaging with the child in playful interactions.

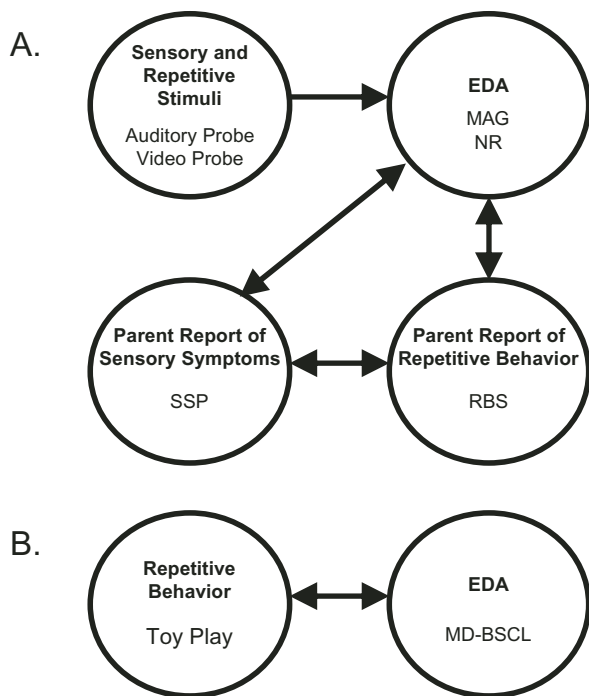


Figure 1. Models of hypothesized relationships between sensory and repetitive stimuli, sensory symptoms, repetitive behavior, and electrodermal activity (EDA) measures. MAG, magnitude of response; MD-BSCL, mean difference from baseline skin conductance level; NR, no response; RBS, Repetitive Behaviors Scale; SSP, Sensory Profile-Short.

Table 1. Participant Characteristics

	CA in months	DQ	ADOS severity score	RBS Total Score	SSP Total Score
ASD ($n = 54$)	39.33 (6.63)	65.91 (24.57)	7.03 (1.67)	27.02 (15.13)	136.12 (17.36)
TD ($n = 33$)	38.85 (7.21)	108.39 (13.17)	N/A	3.19 (4.45)	167.77 (12.72)

ADOS, Autism Diagnostic Observation Schedule; ASD, autism spectrum disorder; CA, chronological age; DQ, developmental quotient; MA, mental age; N/A, not applicable; RBS, Repetitive Behaviors Scale; SSP, Sensory Profile-Short; TD, typically developing.

During that period, and with parental assistance, the experimenter removed the child's shoe and sock, placed the electrode, and quickly replaced the sock. The child and parent were then led to a dimly lit room where a movie was already playing on a computer screen to attract the child's attention. Participants were placed in a "Tripp Trapp" (Stokke®; Alesund, Norway) chair in front of a computer monitor with a parent and the experimenter. As the child watched the movie on the computer monitor, the experimenter finished the electrode lead attachment. Every effort was made to attach the electrodes and leads quickly and with as little interference as possible. The use of a dimly lit room, the close proximity of the parent as the experimenter placed electrodes and attached leads behind the participant, and the use of an interesting video to hold the child's attention appeared to support the child through the procedure. When a child became distressed during this process, either the examiner or the child's parent would distract the child with a toy or snack.

Once the child was properly situated and engaged with the video, the parent moved to the back of the room and was instructed to refrain from initiating interaction with the child. The experimenter sat across from the child. The experimenter minimized interaction with the child by only presenting stimuli and redirecting attention to the computer monitor if necessary. The protocol began with a 2-min baseline period during which the child watched an age-appropriate video on a computer monitor. The protocol then proceeded with a repetitive video probe, sensory probes, and repetitive behavior probe. In addition, the protocol included probes not reported in this paper. The protocol then ended with another 2-min baseline. If a child became upset during the protocol, administration was paused while the parents calmed their child and, on rare occasions, provided snacks or toys. If a child did not calm, that portion of the protocol was aborted.

Repetitive Video Probe

The repetitive video probe consisted of nine, 20-sec video clips with a 1-sec interpicture interval displayed on the computer monitor. The video clips were presented in three different modes: movement, still, and random. The movement clips were either natural movement (i.e. kite flying, bird flying, plant swaying in the wind) or spinning movement (i.e. car wheel rotating, pinwheel rotating, ring spinning). The still segments were static frames of the movement videos. The random clips were the static frames moving around on the screen. At the end of the repetitive video probe, a children's video began to play silently on the computer monitor to maintain the participant's attention during the other sensory probe presentations.

Sensory Probes

The stimuli and presentation were based on a paradigm called the Sensory Challenge protocol [McIntosh, Miller, Shyu, & Dunn, 1999; McIntosh, Miller, Shyu, & Hagerman, 1999; Miller et al., 1999]. The Sensory Challenge protocol has been used in two previous studies in ASD which included older (5 to 15-year-olds) and higher-functioning children and adolescents [Schoen et al., 2008, 2009]. Intraclass correlations (ICCs) from an analysis of test-retest of reliability resulted in ICCs from .16–.83, with most ICCs falling in the moderate range [Schoen et al., 2008]. Adjustments were made to the protocol in the current study because of the young age group of the sample (e.g. background video); therefore, the current study is not a direct replication. Sensory stimuli consisted of auditory (95 decibel siren), olfactory (winter-green oil), visual (strobe light), and tactile (feather) probes. Each of the sensory stimuli was delivered in sets of five, 3-sec presentations with an 8–10 sec interstimulus interval. Sensory presentations were delivered by the experimenter for the olfactory, visual, and tactile stimuli. A research assistant in an observation room administered the auditory probe through the computer sound system. The 95-dB auditory stimulus intensity was confirmed with a sound level meter.

Repetitive Behavior Probe

For the repetitive behavior probe, the experimenter presented the child with four different groups of toys for 1 min each. The groups of toys were seven matchbox cars, a toy train, two plastic rings, and two rhythm sticks. These materials were adapted for toddlers from Ozonoff et al. [2008] and were designed to elicit repetitive play. The coding system was also modified from Ozonoff et al. [2008]. Specific codes of interest were: spinning, lining up, abnormal visual behavior, and repetitive behavior. Any behavior that did not fit these codes was classified as: other toy play, no toy play, or unusable. All codes were duration codes. (See Table 2 for additional code description.) Coding of each segment began when the experimenter placed the toys on the table. This criterion was also used to mark the beginning of each toy play session in the physiology data file. Individually coded variables were collapsed into two categories: typical (i.e. toy play and no toy play) and abnormal behavior (i.e. spinning, lining up, abnormal visual behavior, and repetitive behavior). Coders were trained by the first author to 80% agreement on all codes. Twenty-five percent of both ASD and TD files were double-coded to assess ongoing reliability. Final ICCs ranged from .67 (for the unusable category) to .99 (spins) with an average of .88 across codes. The proportion of time spent engaging in abnormal behaviors was calculated as

Table 2. Descriptions of Toy Play Behavior Codes

Code	Description
Spins	Child drops, tosses, or manipulates an object in order to make it spin or wobble
Lines up	Child lines up objects or precisely aligns or orients object
Unusual visual	Child engages in prolonged visual exploration of an object (≥ 10 sec), examines objects from different angles, in peripheral vision, while squinting, up close, or with eyes closed
Repetitive	Child interacts with object using the same repetitive action for three or more successive actions
Other toy play	Child engages with toy in typical play (e.g. pretending stick is a wand) or other actions (e.g. picking up)
Unusable	Any instance where data could not be coded (e.g. recording issues, parent interference)

Abnormal/(Typical + Abnormal). The unusable code was not included in any further analyses.

Physiological Data Measures

Electrodermal activity was recorded during the entire session using BioPac MP150 Psychophysiological Monitoring System (BioPac Systems Inc., Santa Barbara, CA). Ag/AgCl electrodes were placed on the instep and arch of the right foot, which, like the hand, has extensive innervation of eccrine sweat glands. Plantar placement of electrodes was adopted because of the age, the tactile sensitivities of the population, and the motor demands of the protocol. These methods were based on the procedures used in infant studies of EDA. A study recently validated plantar electrode placement outlined in Cacioppo, Tassinari, and Berntson [2007] in five-month-old infants during a paradigm where the infants sat upright and interacted with an adult [Ham & Tronick, 2008]. In-lab piloting included testing the plantar application on an adult with TD. Reliable responses to sensory, social, and cognitive stimuli were observed. In addition to the electrodes, an accelerometer was attached to each participant's right ankle to measure movement that might contribute to EDA artifact during data collection. Acqknowledge software (version 3.8.1, Biopac Systems Inc) was used to process the electrodermal data.

Tonic measures of EDA. Baseline skin conductance level (BSCL) was defined as the average amplitude of skin conductance across 2 min from baseline 1 and 2 min from baseline 2. For the repetitive behavior probe, skin conductance level was recorded during the four 1-min toy presentations. The variable mean difference from baseline skin conductance level (MD-BSCL) was created by subtracting BSCL from baseline 1 from the average skin conductance level during each 1-min toy play session. The DVD recording of the child's behavior was not time-locked to the Acqknowledge data file, but the beginning and ending of each 1-min session was marked in the data file.

Phasic measures of EDA. For the sensory and repetitive video probes, the magnitude of response (MAG) was recorded as the maximum amplitude of response above .05 micromhos during a 5-sec sampling period occurring 1–6 sec after probe presentation. Trials with no response were included as zeroes. For the repetitive video probes only, the magnitude of response was averaged within condition (i.e. spinning, natural, movement) and presentation mode (i.e. movement, still, random), including trials with no response. In addition, for the repetitive video probes, participants were recoded into EDA response (response $\geq .05$) and no response (trials with no response $\geq .05$) to create a variable labeled no response (NR). During the baseline period for each participant, a section was identified where the participant's incidental excessive movement caused a jagged response above .05. Any data corresponding with movement measured by the accelerometer of the same amplitude was excluded from analysis. In participants with no clear response corresponding to movement during the baseline, .20 volts was used as the maximum movement before the exclusion of phasic EDA data during the video and sensory probes. This cut-off was a conservative estimate based on children with reliable baseline data. Visual attention to the video presentation was live-coded at the time of acquisition and marked in the Acqknowledge file. Segments that were not viewed by participants for at least 3.5-sec were excluded. Of 435 auditory probe trials, 26 were excluded because of movement (6.7%). Out of 1566 trials of the video stimuli, 512 were excluded because of movement or looking time (32.7%). There was no group difference in the number of missing cases for the auditory probe ($t(1) = -1.68, P = .09$) or the video stimuli ($t(1) = 1.48, P = .14$).

Behavioral Measures

Autism Diagnostic Observation Schedule-Generic (ADOS-G). The ADOS-G [Lord et al., 1999] is a semi-structured standardized assessment using developmentally appropriate social and toy-based interactions in a 30–40-min session that elicits symptoms of ASD in four areas: social interaction, communication, play, and repetitive behavior. The ADOS-G was administered to all participants in the study with ASD as part of the diagnostic qualification process. In the present study, modules 1 and 2 were used. To account for differences in the modules, autism severity scores were calculated [Gotham, Pickles, & Lord, 2009]. Autism severity scores range from 1–10 and are based on the total raw score from the administered module and the age of the child.

Autism Diagnostic Interview-Revised (ADI-R). The ADI-R [Lord et al., 1994] is a structured, standardized parent interview developed to assess the presence

and severity of symptoms of ASD. It provides an algorithm that reliably distinguishes children with ASD from those with other developmental delays or with typical development.

Mullen Scales of Early Learning (MSEL). The MSEL [Mullen, 1995] is a standardized developmental assessment for children ranging from 3–64 months of age. The MSEL was administered to all participants according to standard instructions by examiners who were trained in assessing young children with ASD and other developmental disorders. Four subscale scores (i.e. visual reception, fine motor, receptive language, and expressive language) yield standard scores and age-equivalent scores. Developmental quotient (DQ) was computed by dividing the mean age equivalence score by chronological age and then multiplying the result by 100.

Sensory Profile-Short (SSP). The SSP [McIntosh et al., 1999] is a parent report measure of behaviors associated with abnormal responses to sensory stimuli. Items are scored on a 0–4 scale, with lower scores indicating more impairment. In addition to a total score, there are also seven factors: tactile sensitivity, taste/smell sensitivity, movement sensitivity, underresponsive/seeking sensation, auditory filtering, low energy/weak, and visual/auditory sensitivity. The total and subscale scores are classified into three categories based on normative cut-offs: typical performance, probable difference, and definite difference. Scores in the probable difference range are between one and two SDs below the mean for children without disabilities. Scores in the definite difference range are more than two SDs below.

Repetitive Behaviors Scale-Revised (RBS-R). The RBS-R [Bodfish, Symons, & Lewis, 1998] is a parent report rating scale that assesses the existence and severity of various kinds of restricted, repetitive behavior common in people with ASD. The RBS-R has a total score and six subscales: stereotyped behavior, self-injurious behavior, compulsive behavior, ritualistic behavior, sameness behavior, and restricted behavior. The subscales reflect the dimensions of repetitive behavior exhibited by children, adolescents, and adults with ASD.

Data Analysis Plan

Data analyses focused on differences between groups as well as on patterns of response within groups. EDA from baseline 1 and 2 were analyzed with a repeated measures ANOVA. Due to a change in the acquisition procedure for skin conductance midway through data collection, only a subset of participants was included in this analysis (ASD = 23, TD = 19). Only variables based on within-participant change (i.e. MAG and NR) could be compared across the two grounding procedures. All other analyses included the full sample.

For the sensory probes, multilevel models were fit with MAG as the dependent measure. All models were fit using the PROC MIXED procedure in SAS with the maximum likelihood estimation method. This analysis method was chosen to account for missing data because of movement. Maximum likelihood is a best practice procedure to account for missing data with repeated measures [Graham, 2009; Schafer & Graham, 2002]. Because this procedure uses all available data to create estimates of effects, all participants are included regardless of missing values.

For two reasons, the reliability of the sensory probes was evaluated across groups with Cronbach's alpha midway through the data collection. First, three of the probes (i.e. visual, olfactory, and tactile) were administered by the examiner, introducing the potential confound of a social stimuli with the sensory. Second, children (both ASD and TD) sometimes attempted to avoid the presentation of stimuli, particularly the olfactory and tactile, by moving their hands or faces away, resulting in different amounts of probe administration. Because of a low alpha score, the visual probe ($\alpha = .39$) was dropped from the procedure after 37 participants had been through the protocol. The olfactory ($\alpha = .62$) and tactile ($\alpha = .79$) probes were also dropped from the protocol at that time because of concerns about the possible confounding of social and sensory stimuli in the arousal data. The alpha score for the auditory probe was .90 and did not involve presentation by the experimenter. Thus, the data appeared unconfounded and reliable, and are reported here.

The repetitive video probe MAG data were significantly skewed, and we were unable to normalize the distribution through transformation. Therefore, that data was subjected to nonparametric Mann–Whitney comparisons. To explore relationships between the physiological and behavioral measures, planned Spearman's rho correlations were conducted between MAG and behavioral measures including DQ, chronological age, SSP, and RBS-R.

MD-BSCL and the behavioral codes for the 1-min toy play session were highly skewed. Both measures were log-transformed. Differences between groups in repetitive behavior and MD-BSCL were analyzed independently within repeated measures ANOVA. Relationships between these variables were then investigated with correlations.

Results

Behavioral Measures

There were significant differences between the children with and without ASD in parent-reported sensory symptoms on the total score of the SSP ($t(1) = -6.49, P < .001$) and repetitive behavior on the total score of the RBS-R ($t(1) = -7.06, P < .001$). Group differences were also significant on all subscales of both measures. Parents of

children with ASD reported more symptoms on the SSP (resulting in lower scores) and RBS-R than parents of children with TD. In addition to having lower scores overall on the SSP, the children in the ASD group also had more variability according to Levene's test of equality of variances ($F(1, 79) = 4.33, P < .05$). In the ASD group, 56% fell in the most severe category (definite difference) on the SSP, indicating that nearly half of the parents in the ASD group reported less severe or minimal symptoms in their children. Varying portions of children in the ASD group were categorized into the severest range across all subscales (14–67%). Only 3% (one child) of the TD group were reported to be in the severe category. Very few children in the TD group were ever within the severest range (0–6%) across the subscales,

Comparisons between parent report measures in the ASD and TD groups revealed that scores on the SSP and RBS-R were correlated within both the ASD ($r = -.48, P = .001$) and TD ($r = -.40, P < .05$) groups. There was no difference between the groups in the correlation between these measures according to Fisher's Z test ($Z = -.37, P = .71$).

Baseline

Group difference in BSCL from baseline 1 and 2 was tested as a main effect within a repeated measures ANOVA. There was no significant effect of time (i.e. pre versus post) ($F(3,87) = 2.07, P = .11$) or significant difference between diagnostic groups ($F(3,87) = .091, P = .90$). Group difference was also tested in the other subsample with the same results.

Sensory Probes

Three multilevel models were tested for the auditory probe: no growth, linear, and quadratic growth. Diagnostic group was included in the model and coded as 0 for ASD and 1 for TD. For the linear and quadratic models, trial was entered as the measure of time, 0 through 4. All models included a random intercept and slope when applicable. Goodness of fit was tested by a chi-square log-likelihood deviance test (Table 3). The best fitting model was the quadratic model; however, diagnostic group and the interaction between diagnostic group and time did not improve model fit (see Table 4 for estimates), indicating no significant group difference in the intercept (response on trial 1) or across time. Group differences were further explored by recentering the data at each trial, but there was no group difference in response on any trial. Both groups had significantly decreased responses—demonstrating habituation across the first three trials, as indicated by a significant negative slope ($\beta = -0.15, P < .01$). Both groups also had a slight increase

Table 3. Chi-Square Fit Statistics of Magnitude of Response (MAG) to Auditory Probes

Model	Effect	-2 log-likelihood	df	$\Delta\chi^2$
No growth		409.3	4	
	Group	409.2	5	0.1
Linear slope		386.8	8	
	Group	386.7	9	0.1
Quadratic slope	Group × slope	385.7	10	1.0
		362.7	13	
	Group	362.6	14	0.1
	Group × Slope	359.8	16	2.8

Table 4. Parameter Estimates of Best Fitting Model for MAG to Auditory Probes

Effect	Estimate	SE	DF	t	P
Intercept	0.53	0.06	85	9.25	<.0001
Linear slope	-0.15	0.04	315	-3.23	<.01
Quadratic slope	0.02	0.01	315	2.48	0.01

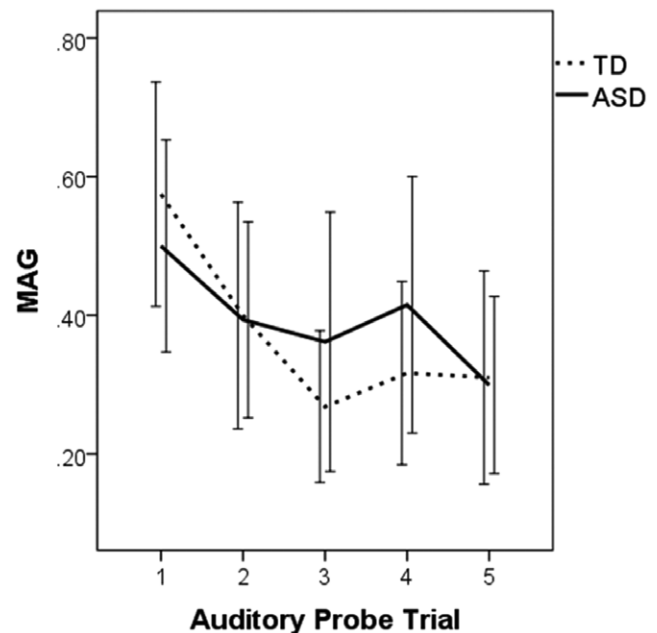


Figure 2. Magnitude of response (MAG) to auditory probes across trials. ASD, autism spectrum disorder; TD, typically developing.

across the last two trials as indicated by the significant positive quadratic effect ($\beta = 0.02, P < .05$) (Fig. 2).

Sensory Probes and Behavioral Measures

Correlational analyses were conducted to test for relationships between MAG for the auditory probe and behavioral measures, specifically DQ, chronological age,

auditory filtering, visual/auditory sensitivity subscales and total score from the SSP and the total score from the RBS-R. None of the behavioral measures was significantly correlated with average MAG.

Repetitive Video Probes

MAG for the repetitive video probes had a highly skewed distribution which could not be corrected by transforming the data. The skewed distribution was mainly caused by high numbers of participants who had no peak amplitudes above 0.05 micromhos to the probes. All comparisons were made with nonparametric Mann–Whitney tests. No significant differences between the groups were found. Differences between the groups in NR were also explored using chi-square analyses. No significant group differences in response category were found between groups for the spinning videos, $\chi^2(1) = .05, P = .82$ or the natural videos, $\chi^2(1) = .32, P = .57$. Within-group comparisons of both the ASD and TD groups for MAG and NR revealed no significant differences between spinning and natural movement videos in any presentation mode (i.e. moving, still, or random).

Repetitive Video Probes and Behavioral Measures

We examined the association within each group of MAG with behavioral measures (DQ, chronological age, total score from the SSP, and the total score from the RBS-R) for the repetitive video probes. Only 1 out of 32 correlations run between the two groups was significant. Children in the ASD group who had higher MAG responses while viewing the spinning videos also scored higher on the total score of the RBS-R ($r = .34, P = .04$). Given the number of correlations analyzed, this could be a chance finding.

Repetitive Behavior Probes

Group difference on proportion of time spent engaging in repetitive behavior during the play probe was tested as a main effect within a repeated measures ANOVA. Tests of between-subjects effects revealed no significant group difference ($F(3,195) = .84, P = .47$). In the repeated measures ANOVA with MD-BSCL as the dependent measure, there was also no significant group difference ($F(3, 177) = 0.96, P = .41$). Correlations between behavior and MD-BSCL were not significant.

Discussion

The aims of the current study were: (1) to develop a procedure for examining EDA measures that could be used with very young children; (2) to compare phasic measures of EDA between groups of young children with

ASD and with typical development in response to sensory and repetitive stimuli; (3) to examine relationships between EDA and parent reports of sensory symptoms and repetitive behaviors; and (4) to test for relationships between tonic EDA and observed repetitive behaviors. The parents of children with ASD reported significantly more sensory symptoms and repetitive behaviors in their children. However, there were no differences between children with ASD and children with TD in any measure of EDA during any of the probes. Out of the many correlations between EDA and behavioral measures that were explored, only one was significant, and it should be interpreted with caution.

Methodological Considerations

To accomplish the first aim of this study, we had to manage several significant methodological challenges to gather the data. The first challenge was to help children tolerate electrode placement and voluntarily leave the electrodes in place. We introduced the children to the electrodes in the waiting room. We also had the parent play an active role in helping adapt the electrode placement procedures according to the specific sensitivities of the child. We surreptitiously placed the electrode leads to the sole of the right foot in a darkened room while the child sat on a toddler chair watching a video. Electrode placement was accomplished through distraction techniques, the only restraint being the standard safety lap belt in the toddler chair.

The second challenge was to manage the data resulting from random foot movements of the children during recording. Children wore an accelerometer on the ankle. Recordings of movement were taken during the entire protocol. A strict data cleaning process removed portions of the data that were associated with movement that could produce EDA artifact or otherwise affect data collection. Care was also taken during collection to make notes within each data file when acquisition was compromised.

The third challenge was to maintain the children's cooperative state during the multiple sensory exposures. We played children's videos without sound on the monitor on the table in a relatively dark room throughout the experiment. The video acted to maintain the children's attention, enabling them to stay in their seats and participate in the experiment throughout the session. Only 8 of 62 children with ASD did not tolerate these procedures. Thus, the methods used resulted in a relatively high level of tolerance for the procedure.

Despite efforts in facilitating children through the protocol, some children were unable to complete the session successfully. Many children displayed some immediate reactions to the electrodes and probes, and parents varied in their willingness to continue their efforts if their child

became upset. Alterations to the protocol might help more children complete the protocol. For example, experimenters might reduce the number of lead attachments (e.g. no accelerometer) or use a high chair with an attached tray that would prevent children from reaching down and pulling off the electrodes. However, the high rate of data collection demonstrates the success of the procedures we developed.

The final set of challenges involved administration of the sensory probes. The auditory and repetitive video probes appeared to be the most successful because they were administered via computer and thus required no social interaction. The tactile, olfactory, and strobe light probes all involved a human experimenter administering the sensory probe. Interpretation of these responses was confounded by the possibility that the children's responses were influenced by their reactions to a social agent. The data from these probes demonstrated unacceptable variability from one press to the next for children in both groups as manifested by low Cronbach's alpha scores. In another study, adolescent participants with ASD also demonstrated high variability in phasic EDA to sensory stimuli. However, the authors in that study did not discuss the social delivery of probes as a potential confound [Schoen et al., 2008]. Evidence from a study of behavioral responses in children with ASD suggests that children with ASD demonstrate a more severe pattern of hypo-responsiveness to social versus nonsocial stimuli [Baranek et al., 2013]. We interpreted the lack of consistent individual response patterns in the current sample as indicating problems with the stimulus delivery method. Future studies should carefully control and compare EDA responses to sensory stimuli from social and nonsocial sources.

Sensory Symptoms, Repetitive Behavior, and EDA

Consistent with the current literature, parents of children with ASD reported significantly more sensory symptoms and repetitive behaviors in their children than did parents of TD children. According to parent report, the ASD group showed heterogeneous patterns of responses. Many of the parents reported severe symptoms on the SSP within all three behavioral profiles: hyper-responsivity, hypo-responsivity, and sensory seeking. In both the ASD and TD groups, children who were reported to exhibit more sensory symptoms were also reported to have more repetitive behaviors. Other studies have identified the relationship between sensory symptoms and repetitive behaviors utilizing parent report and observational measures [Boyd et al., 2010; Boyd, McBee, Holtzclaw, Baranek, & Bodfish, 2009; Gabriels et al., 2008]. The relationship between sensory symptoms and repetitive behaviors supports a potential shared mechanism between these two symptoms.

The ASD group did not significantly differ from the TD group in baseline tonic skin conductance level. Visually, distributions were similar in both groups with no indication of high and low skin conductance level subgroups. These results suggest typical levels of sympathetic nervous system arousal in this group of children with ASD. This finding differs from previous studies that reported lower tonic arousal in groups with ASD [Schoen et al., 2009] and studies that reported two patterns of EDA within ASD [Hirstein et al., 2001; Schoen et al., 2008]. The sample used in this study differs from previous studies in two significant ways. The sample in this study consists of young children with ASD across a wide range of functioning; whereas, previous research featured older, higher-functioning samples. If replications and extensions of this study with young children continue to demonstrate the current findings, one possible explanation for the variance from previous findings involves a developmental change in arousal from early childhood to middle or late childhood in ASD.

In contrast to one of our hypotheses, young children with ASD did not differ significantly from the group with TD controls in their magnitude of response to intense auditory stimulation or in the extent and speed of habituation. Both groups demonstrated similar patterns of habituation over repeated sensory exposures to auditory stimuli. The responses of both groups to the auditory probe were quite consistent over time, resulting in highly reliable data. Our ASD group's findings are similar to those reported previously in studies of phasic EDA in ASD [Schoen et al., 2008, 2009]. Taken together with previous studies using a similar protocol, the present results suggest that, as a group, children with ASD do not differ from TD peers in their phasic EDA responses to intense nonsocial auditory stimuli. Children with ASD do not demonstrate overreactivity, underreactivity, or difficulty with habituation. These results do not provide support for over- and under-arousal theories of sensory symptoms in ASD, at least in the case of loud auditory stimuli which is one of the most often reported symptoms in children with ASD.

MAG to the auditory stimulus appeared to be unrelated to most other variables. DQ, chronological age, parent-reported repetitive and stereotyped behavior on the RBS-R and sensory symptoms on the SSP showed no correlation with MAG to the auditory stimulus. This lack of association held even for the auditory filtering and visual/auditory subscales of the SSP. In future studies, investigators should consider testing a range of different auditory stimuli presented at different sound levels to identify possible auditory conditions that may elicit differential responding in ASD. Alternatively, there is increasing evidence suggesting specific subgroups of sensory responders within ASD; however, due to the sample size of the current study, we were unable to separate our ASD group into subgroups.

The repetitive video probes reflected repetitive movements of particular objects that are often associated with the interests of children with ASD (e.g. spinning car wheel), as well as naturally moving objects (e.g. bird flying). These stimuli were computer-delivered and so avoided the problem of social delivery. In contrast to our hypotheses, there was no difference in MAG between groups across conditions involving repetitive stimuli. Within-group comparisons of responses to the various conditions were non-significant except for one—only the ASD group had a significant association between MAG to the spinning videos and parent reports of repetitive behaviors. However, this association may be due to chance based on the number of correlations explored. In this study, we chose to present moving objects via video presentation in order to ensure consistent exposure across participants. It is possible that we elicited a less robust MAG response than might have been obtained through direct exposure to movement, including spinning objects.

Finally, there was no difference between groups in MD-BSCL when engaging in repetitive toy play and no relationship between arousal and abnormal repetitive behaviors. These findings were, again, in contrast to our hypotheses. Surprisingly, there was no difference in the duration of repetitive behaviors between the groups. Both groups engaged in some repetitive behaviors; however, our protocol failed to elicit the usual group difference consistently documented in the literature.

Findings from the present study combined with previous research lead to two main points. First, correlation analyses between parent reports of sensory symptoms and repetitive and restricted behaviors replicate previous findings from parent report measures in children and adolescents with ASD, demonstrating that these two symptom sets are related and may, therefore, have similar underlying mechanisms [Boyd et al., 2009, 2010; Gabriels et al., 2008]. Second, according to our findings, neither kind of symptom appears to reflect abnormalities of SNS arousal as elicited in this lab situation and measured in reactions to specific intense sensory stimuli or in general level of arousal while playing with toys. These findings are consistent with a previous study of sensory reactivity in ASD that found no significant correlations between lab-based measures of physiological reactivity and parent report of sensory symptoms [Schoen et al., 2009]. Together these two studies represent samples of children with ASD across multiple ages and functioning levels.

Limitations

These findings should be considered in light of the limitations inherent in this study. One limitation was that the current sample of children with ASD was heterogeneous in terms of parent-reported symptom profiles as well as

sensory responsivity. Within ASD, there is some evidence for subgroups with different patterns of sensory symptoms, but our sample size was not large enough to examine this statistically [Lane, Young, Baker, & Angley, 2010; Schoen et al., 2008]. Future studies should either recruit children with specific response patterns or include samples large enough to use data-driven analysis methods to identify subgroups of physiological or behavioral responders. A second limitation in the findings was the accommodation of the video playing in background with no sound used to facilitate successful completion of the protocol. This may have distracted children from the sensory and repetitive probes. A third limitation arose around inconsistent phasic EDA to the sensory probes which prevented the analysis of several sensory domains.

A fourth limitation was that children with ASD may have sensitivities to specific stimuli and/or contexts which we were unable to test within the laboratory setting of this protocol.

The fifth limitation was that our repetitive behavior probe was unable to elicit the usual difference in repetitive behaviors between the ASD and TD groups. This lack of group difference may have been a factor in finding a lack of relationship between MD-BSCL and repetitive behavior. Although the SSP is a widely used measure, neither the auditory filtering subscale nor the visual/auditory sensitivity subscale was a pure measure of sensory symptoms to nonsocial auditory stimuli. This lack of specificity may have been a factor in the lack of correspondence between parent report and our phasic measure of EDA. The last limitation was that we were unable to directly time-lock the behavioral video coding of repetitive behavior with the electrodermal data. However, the same criteria were used to mark the beginning of each session live in the electrodermal file and in the video for the repetitive behavior coding. We used averaged measures across the entire minute to account for the potential of any small discrepancies in the marking of either file. Future studies should examine arousal before, during, and after engaging in repetitive behavior. Examining arousal in this way would allow researchers to collect physiological measures and repetitive behavior in a synchronous manner. With synchronous measures, researcher could explore measures of both tonic and phasic EDA.

Conclusion

Many have questioned whether certain abnormal ASD behaviors are associated with autonomic dysregulation. Measurement of autonomic function in young children with ASD is quite challenging, but we were able to develop a method for addressing these difficulties. We found no group differences in response to any of the

sensory stimuli. We also found very few relationships across different sensory measures or between sensory symptom and repetitive behavior variables in the ASD group. Both of these findings do not support an association between physiological arousal and sensory symptoms or repetitive behaviors in ASD. Our findings suggest the need for future studies that explore other potential underlying mechanisms of these symptoms. For example, there is increasing evidence of abnormal neurological processing of sensory input within people with ASD both at basic levels and at higher level multi-sensory integration [Brandwein et al., 2013; Foss-Feig et al., 2010; Marco, Hinkley, Hill, & Nagarajan, 2011]. Newer methods, new hypotheses, and well-designed experiments will provide more answers in the future to this set of puzzling symptoms in ASD.

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