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Behavioral and Physiological Responses to Child-Directed Speech of Children with Autism Spectrum Disorders or Typical Development

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Abstract

Young boys with autism were compared to typically developing boys on responses to nonsocial and child-directed speech (CDS) stimuli. Behavioral (looking) and physiological (heart rate and respiratory sinus arrhythmia) measures were collected. Boys with autism looked equally as much as chronological age-matched peers at nonsocial stimuli, but less at CDS stimuli. Boys with autism and language age-matched peers differed in patterns of looking at live versus videotaped CDS stimuli. Boys with autism demonstrated faster heart rates than chronological age-matched peers, but did not differ significantly on respiratory sinus arrhythmia. Reduced attention during CDS may restrict language-learning opportunities for children with autism. The heart rate findings suggest that young children with autism have a nonspecific elevated arousal level.

Keywords

autism; language; child-directed speech; attention; respiratory sinus arrhythmia; heart rate

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Although the language outcomes of children with autism spectrum disorders (ASD) are highly variable, as a group these children are at great risk for lifelong impairments in broad aspects of language competence (Lewis, Murdoch & Woodyatt, 2007; Loucas et al., 2008; Mawhood, Howlin & Rutter, 2000). Further, success in acquiring communicative speech by children with ASD as preschoolers is one of the strongest predictors of better adaptive outcomes as adults (Luyster, Qiu, Lopez & Lord, 2007; Szatmari, Bryson, Boyle, Streiner & Duku, 2003; Venter, Lord & Schopler, 1992). Thus, a better understanding of prelinguistic factors that may be associated with the acquisition of language development in this population is important to the goal of improving long-range outcomes. One such factor is the extent to which children attend to speech directed to them. Such attention to child-directed speech (CDS) is the focus of the current study. The rationale for the investigation is based on previous evidence from several lines of research indicating: (a) CDS is associated with social interaction and the language acquisition process among typically developing children; (b) children with ASD show decreased attention to CDS; (c) vagal activity and heart rate are

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indices of physiological states that may provide information about the quality of children's attentional processing; (d) the physiological responses of children with ASD differ from those of children without ASD; and (e) behavioral and physiological responses of children with ASD to CDS predict later language outcomes.

Role of CDS in Typical Development

CDS is characterized by many differences compared to adult-directed speech, including higher pitch, greater pitch range, shorter sentences, elongated vowels, more repetition, less diversity in vocabulary, and more references to the "here-and-now" (for a review, see Pine, 1994). CDS plays several important roles in child-caregiver interactions, such as promoting the affective relationship between adults and young children (Trevarthen & Aitken, 2001), selectively engaging children's attention (Cooper & Aslin, 1990), and enhancing children's learning of word boundaries (Thiessen, Hill & Saffran, 2005) and language-specific phonetic categories (Werker et al., 2007). Taken together, this literature suggests that children's responses to CDS may have a significant impact on language development.

Responses to CDS in Children with ASD

Children with ASD attend to CDS less than other young children do, reducing potential opportunities to benefit from its unique features. Different components of attention may impact the responses of these children to CDS. The failure of children with ASD to respond promptly to someone calling their name (Baranek, 1999; Lord, 1995; Osterling Dawson & Munson, 2002) likely reflects deficits in orienting, conceptualized as an involuntary, reactive phase of attention immediately following a novel stimulus onset (Posner & Petersen, 1990; Richards, 1987). Orienting to CDS clearly is an important step in processing such stimuli. Beyond orienting, however, children arguably need to maintain attention to CDS in order to benefit from it.

In the current investigation, consistent with other research with infants and young children (Ruff, Capozzoli & Weissberg, 1998; Shaddy & Colombo, 2004), the term "sustained attention" refers to the child's ability to maintain concentration as reflected in the duration of looking at stimuli. In research with older children and adults, measures of sustained attention more commonly examine attentional vigilance, requiring that children monitor ongoing information for particular targets (Sanders, Johnson, Garavan, Gill & Gallagher, 2008). In both types of studies, however, the maintenance of attention to particular stimuli is considered voluntary, requiring regulation of attention through cognitive control (Posner & Petersen, 1990; Richards, 1987). The development of voluntary attention control toward the end of the first year of life has been linked to later language development in typically developing children (Kannass & Oakes, 2008).

In comparison to children who are typically developing, children with ASD have difficulty in disengaging their attention from a stimulus to shift focus (Zwaigenbaum et al., 2005; Landry & Bryson, 2004). Reviewing research primarily completed with older children using vigilance paradigms, Sanders et al. (2008) concluded that children with ASD do not have a generalized deficit in sustaining attention. In studying attention to objects versus people, however,Swettenham et al. (1998) found that toddlers with ASD looked longer at objects and less at people than children in comparison groups. In addition, toddlers with ASD shifted attention more between objects, but less from objects to people or people to people than their peers without ASD. Thus, the social versus nonsocial nature of the stimuli may play a role in attention control in this population.

Research with young typically developing children has suggested that cross-situational variability in sustained attention may be partly attributable to motivation (Ruff et al., 1998).

Social stimuli (such as CDS) may be inherently less motivating for children with ASD than nonsocial stimuli. This assumption is supported by findings that children with ASD have less preference for attending to CDS over nonspeech stimuli than peers without autism (Klin, 1991; Kuhl, Coffrey-Corina, Padden & Dawson, 2005; Paul, Charwarska, Fowler, Cichetti, & Volkmar, 2007). A possible alternative explanation was raised in the study by Paul et al. (2007), however, whose findings suggested that the strength of children's preferences for CDS is related to developmental language level independent of diagnosis. Additional group comparison investigations examining factors influencing children's attention to CDS are warranted to replicate and extend the limited research in this area, and explore implications for language development and intervention with children with ASD.

Physiological Correlates of Attention

Measures of physiological activity during attention tasks may capture different aspects of or influences on attention quality than behavioral measures. To date, however, physiological correlates of attention to CDS have received limited attention.

Different phases of attention are associated with characteristic physiological correlates. For example, behavioral indications of sustained attention in infants and young children, such as quieting and looking, are associated physiologically with a slowing of heart rate (e.g., Richards & Cronise, 2000). Heart rate is impacted by both the sympathetic and parasympathetic systems, which can have reciprocal, coactive, or independent effects (Berntson, Cacioppo & Quigley, 1993). Heart rate changes during different attention phases appear to be mediated more by the parasympathetic than the sympathetic system (Richards & Casey, 1991). Parasympathetic system influences on the heart often are studied through measuring respiratory sinus arrhythmia (RSA) as an index of vagal activity. In a resting state, heart rate varies depending on the phase of the respiratory cycle, with an increase in heart rate on inspiration and a decrease in heart rate on expiration. The difference between the heart rate during inspiration versus expiration constitutes RSA and reflects the influence of the vagus nerve in regulating the heartbeat. A larger RSA reflects greater vagal activity and a smaller RSA reflects lower vagal activity.

Previous studies with children have examined the association of RSA with sustained attention. Both infants and school-age children have demonstrated a decrease of RSA in stimulus conditions designed to create more cognitive load (Pizur-Barnekow, Kraemer, & Winters, 2008; Suess et al., 1994). A study of infants by Bazhenova, Plonskaia & Porges (2001) may have the most relevance to the current study, as it examined RSA changes in infants in conjunction with baseline, object-mediated, and person-mediated conditions. The object-mediated conditions displayed pictures and then a toy in the infant's visual field; the person-mediated conditions included a still face presentation followed by social interaction (with no touching). The infants showed an increase in RSA from baseline to the object-mediated conditions. Thus, sustaining attention to stimuli in otherwise undemanding contexts was associated with an increase in RSA level compared to baseline. In the person-mediated conditions, infants showed a decrease in RSA and increase in negative emotion in response to the still-face, and then a return to higher levels of RSA (similar to those associated with the object-mediated conditions) during social interaction. Being contrary to their usual experiences in face-to-face interactions, the still-face likely created the most cognitive dissonance for infants, and also elicited a negative emotional reaction. Thus, the separate associations of RSA with cognitive demand and negative social-emotional experience are not clear.

In light of the findings of Bazehnova et al. (2001), and due to the social deficits of children with ASD, the association of RSA with social-emotional development in children is relevant to the current study. Higher RSA under nonchallenging, calm conditions in infancy predicts greater sociability during the toddler and preschool years (Fox, 1989; Porges, Doussard-Roosevelt, Portales & Suess, 1994). Among preschoolers, higher RSA in nonchallenging conditions is related to higher concurrent social competence, better emotion regulation, and lower levels of problem behavior (Blair & Peters, 2003; Calkins, 1997; Doussard-Roosevelt, McClenny & Porges, 2001; Porges et al., 1994).

Both heart rate and RSA show age-related changes across the age range of participants in the current investigation (e.g., Porges et al., 1994), making the inclusion of a chronological age-matched comparison group in the current study important for interpretation of the physiological data.

Autonomic Measures and Children with ASD

Several older studies reported comparable mean heart rate for children with autism compared to peers without autism (e.g., Graveling & Brooke, 1978; Hutt, Forrest & Richer, 1975; Lake, Ziegler & Murphy, 1977), but some recent studies have found a higher heart rate in children with autism under resting conditions (Bal et al., 2010; Goodwin et al., 2006; Kootz & Cohen, 1981) and in varied stressor conditions (Goodwin et al., 2006). Considerable research has addressed the possibility that children with ASD have baseline levels of hyperarousal and/or experience hyperarousal in reaction to varied stimulus conditions. Most of these studies have used skin conductance measures as an index of arousal or sympathetic activity level. Findings have been variable, with evidence for (Hirstein Iverson, & Ramachandran, 2001) and against (Schoen, Miller, Brett-Green & Nielson, 2009) generalized hyperarousal among children with ASD compared to typically developing children of comparable chronological ages, and for (Dalton et al., 2005) and against (Corona, Dissanayake, Arbelle, Wellington & Sigman, 1998; Hirstein et al., 2001) social-specific hyperarousal. Arousal levels have been tied theoretically (Yerkes & Dodson, 1908) and empirically to learning (Markham, Toth & Likliter, 2006) and coping with stress (Oldehinkel, Verhulst & Ormel, 2008). Thus, clarification regarding whether children with ASD experience generalized hyperarousal, social-specific hyperarousal, or both could have implications for models related to processing of CDS by children with ASD.

Children with ASD have exhibited reduced levels of baseline RSA compared to controls (Bal et al., 2010; Ming, Julu, Brimacombe, Connor & Daniels, 2005; Vaughan van Hecke et al., 2009), as well as diminished adaptation in RSA during tasks with cognitive demands (Althaus, van Roon, Mulder, Mulder, Aarnoudse & Minderaa, 2004; Toichi & Kamio, 2003).Ming et al. (2005) suggested that deficits in parasympathetic function among children with ASD may result in relatively unrestrained sympathetic activity. Participants have been school-aged children and adolescents, and the generalizability of these findings to toddlers or preschoolers with ASD has not been determined.

Attention to CDS and Language Development in Children with ASD

The current investigation assumes that maintaining attention to CDS is essential for child language learning. This assumption is supported by several previous studies.Kuhl et al. (2005) found that a subgroup of preschoolers with ASD who preferred CDS to a nonspeech analog showed better performance in a speech discrimination task than their counterparts with ASD who preferred listening to nonspeech stimuli. A study of toddlers with ASD found significant concurrent and predictive correlations between attention to CDS and receptive language abilities (Paul et al., 2007). A previous, longitudinal study with the cohort of children with ASD included in the current study similarly found concurrent and predictive associations between attention to CDS and both receptive and expressive language skills (Watson, Baranek, Roberts, David, & Perryman, 2010). In addition, higher RSA during CDS (but not during nonsocial stimuli) accounted for unique variance in expressive language and social-communication adaptive outcomes of the children one year later, after accounting for initial language levels. Thus, consistent with findings for other populations, higher RSA under a nonchallenging condition appears to be a positive prognostic indicator for better social-communicative outcomes in children with ASD, but the finding regarding the specificity of RSA during CDS as a predictor was novel. The findings in this study suggested that RSA during CDS indexes some aspect of language processing not captured by measures of time spent looking at CDS stimuli.

Previous studies have not examined whether measures of physiological responses for children with ASD during CDS differ from those of their typically developing peers. Given the predictive association between both behavioral and physiological responses during CDS and later language outcomes among young children with ASD, comparing the responses of children with ASD during CDS to those of their typically developing peers may assist in developing better models of language development among young children with ASD.

Purpose of the Study

The over-arching focus of this study was to examine behavioral and physiological responses to CDS among young children with ASD who had no or limited expressive language, and typically developing peers matched for chronological age (TCA group) or language age (TLA group). Specifically, we examined the extent to which children with ASD and children in typically developing comparison groups differed in responses to CDS stimuli in terms of (a) amount of looking, (b) RSA, and (c) heart rate. We included a contrast nonsocial condition as well, to aid in interpretation of our data. We hypothesized the following:

1. Children with ASD will look less (i.e., show decreased sustained attention) during CDS conditions than comparison groups, but will not show differences in looking at nonsocial stimuli. This hypothesis is based on prior evidence that children with ASD fail to show the expected preference for CDS over other stimuli, but do not show a deficit in sustaining attention to nonsocial stimuli.
2. Children with ASD will show higher heart rate than the TCA group during both CDS and nonsocial conditions. This hypothesis is based on prior evidence supporting generalized hyperarousal among children with ASD compared to typically developing peers of the same age.
3. (a) Children with ASD will show lower levels of RSA than the TCA group during CDS and nonsocial conditions. This hypothesis is based on prior evidence that lower RSA is concurrently and predictively associated with poorer social behavior in other populations, and prior evidence of parasympathetic functioning deficits among children with ASD. (b) An interaction effect will be observed between CDS and nonsocial stimuli, such that the TCA children will show similar RSA levels during CDS and nonsocial stimuli, whereas children with ASD will show lower RSA for CDS stimuli relative to their RSA during nonsocial stimuli. This hypothesis is based specifically on the findings of Bazhenova et al. (2001) who found that RSA was lower in infants presented with a social condition that caused them some distress. We anticipated that young children with ASD would find CDS stimuli more unpleasant and challenging than nonsocial stimuli, but that the TCA group would experience both types of stimuli positively.

Methods

Participants

Twenty-three boys diagnosed with ASD were recruited; one was unable to complete any of the experimental protocol, leaving 22 participants with ASD. These children ranged in age from 29 to 42 months. For comparison, 15 typically developing boys ranging in age from 6 to 18 months were recruited as a language age comparison group (TLA), and a separate group of 14 typically developing boys ranging in age from 22 to 41 months were recruited as a chronological age comparison group (TCA).

Inclusion criteria for the ASD group were: (a) an existing clinical diagnosis of an ASD by a licensed psychologist or physician; (b) an expressive communication age equivalent (AE) of less than 24 months at entry on the *Preschool Language Scale, 4th edition* (Zimmerman, Steiner & Pond, 2002); (c) absence of a co-occurring condition (neurological or genetic disorder such as Rett syndrome, tuberous sclerosis, or fragile X); (d) vision and hearing acuity within normal or corrected normal ranges; and (e) English spoken as the primary language in the home. Autism diagnoses were confirmed at study entry with the *Autism Diagnostic Observation Schedule* (ADOS; Lord, Rutter, Dilavore, & Risi, 1999) and the *Autism Diagnostic Interview-Revised* (ADI-R; Rutter, LeCouteur & Lord, 2003). Twenty participants met the cut-off for “autistic disorder” on both confirmatory measures; two additional subjects met the cut-off for “autism spectrum” on the ADOS; these latter two participants did not meet criteria for “autistic disorder” on the ADI-R, and at the time they were evaluated, the ADI-R did not provide cut-offs for other diagnoses on the autism spectrum.

Inclusion criteria for the typically developing children were: (a) performance within normal limits on the *Mullen Scales of Early Learning* (MSEL) (Mullen, 1995), the PLS-4 (Zimmerman et al, 2002), and the *Vineland Adaptive Behavior Scales* (VABS) (Sparrow, Balla & Cichetti, 1984); (b) no history of diagnosed or suspected developmental disabilities based on parental report; (c) vision and hearing acuity within normal or corrected normal ranges; and (d) English spoken as the primary or only language within the home. Children receiving psychopharmacological treatments were excluded from the study because of possible effects of medications such as stimulants and psychotropics on attention and physiology.

Descriptive data for the three groups are provided in Table 1. Demographically, the mothers of the participants self-identified as Caucasian (83%) or African-American (17%). A plurality of the mothers had obtained at least a bachelors degree (48%), followed by those whose highest level of education was a high school diploma/GED (39%), and those who had obtained an associate’s degree (13%). Families received $25 for participating in this part of the study, and reimbursement for transportation costs. The children themselves also received a small toy or book for their contributions.

Measures of Responses to Nonsocial and CDS stimuli

The nonsocial stimulus condition consisted of a music video comprised of digitized classical music accompanied by nonsocial visual images (moving toys, visual patterns). The target length of the nonsocial stimulus condition was two minutes. The CDS condition included three different CDS vignettes: (a) Video Story, a video of a female actor reading out of a novel storybook, as if reading to the child (book facing outward, actor directly facing camera); (b) Puppet Show, a live puppet show script performed by a female research assistant; and (c) Video Toy, a video of a female actor playing with and describing a novel toy using nonsense words. The target length for each of these CDS vignettes was one minute. The behavioral measure of responses to the stimuli was the proportion of the time the child sustained looking at the target stimuli. Sustained looking was coded only when the child looked for at least two consecutive seconds. We computed a proportion of sustained looking for the nonsocial condition and each of the three CDS vignettes; these proportions were computed as the number of seconds of sustained looking divided by the total number of seconds of each stimulus vignette. In addition, we computed a mean proportion of sustained looking during the CDS condition by adding the proportions for the three CDS vignettes and dividing by three. Proportions were used as the metric, rather than duration (i.e., number of seconds), to facilitate comparisons across conditions and across CDS vignettes. This was necessary due to a difference in the length of the nonsocial condition (2 minutes) versus the CDS condition (approximately 3 minutes for the combined vignettes), minor variability in length of conditions due to reaction time differences in the research assistant's activation of the switch to mark the beginning and end of each condition or vignette, and more notable child-to-child variability in the exact number of seconds of the live presentation of the Puppet Show. For the Puppet Show, although the research assistant rehearsed the script to fit into a 60-second time interval, the actual presentation of the script in the presence of children lasted an average of 70.3 seconds, with no significant difference based on group (ASD mean = 69.5 s [*SD* = 4.8], TLA mean = 69.6 s [*SD* = 3.7], TCA mean = 72 s [*SD* = 2.2]; *F*[2] = 1.9, *p* = .15).

The three CDS vignettes were developed as a small scale of CDS stimuli (delivered by different speakers and with different content) that would yield a reliable measure of attention to CDS for children with ASD. Reliability analyses for the three-item scale yielded a Cronbach's alpha of .838 for sustained attention responses in the ASD group, and a Cronbach's alpha of .773 for all groups combined, supporting the idea that the CDS vignettes function reliably as a scale.

Heart activity was collected using the Mini-Logger 2000 (1994). Physiological measures included heart period or inter-beat-interval (IBI) and RSA. IBI has an inverse relation to heart rate, with greater IBIs reflecting a slower heart rate. Continuous records of IBI were recorded throughout the experimental session. Mean IBI was computed during sustained looking for (a) the nonsocial condition and (b) the combined vignettes comprising the CDS condition.

RSA was derived from the continuous recording of IBIs during the children's exposure to the stimuli in the nonsocial and CDS conditions, irrespective of whether the child was looking at the stimuli. RSA was computed for the nonsocial condition and for the three CDS vignettes combined (see procedures below). We used the mean RSA across the three one-minute CDS vignettes as a dependent variable due to previous evidence that continuous short samples of heart activity are less reliable than either longer samples or multiple short samples separated by intervals of time (Richards, 1995). The strategy of using longer samples was precluded by the ages and functioning levels of our participants, particularly the ASD and TLA groups, so we chose the strategy of using multiple short samples instead. The use of a mean RSA from different tasks tapping the same construct is consistent with previous research (Alkon et al., 2006; Graziano, Keane & Calkins, 2007; Marcovitch et al., 2010).

Procedures

Participants with ASD were recruited from two sources: (a) a research registry of families with a child with ASD; and (b) a larger, collaborating research project recruiting children with ASD in the same age range. These referral sources distributed recruitment flyers to the parents of potential participants, and received responses from families willing to be contacted about the current study. Typically developing participants were recruited through the collaborating research project, via a broadcast email to the university community, and via word-of-mouth. Project staff determined that children met preliminary eligibility criteria through a telephone interview, obtained verbal consent for participation, and scheduled an appointment. Parents received a packet by mail that included consent forms, rating scales, demographic information, and sample electrocardiogram (ECG) electrodes to use to familiarize the child participant with this aspect of the study procedures. Completed forms and questionnaires were collected when the family came to the research laboratory for the assessments. The Institutional Review Board at the University of North Carolina at Chapel Hill approved the project.

Assessments were typically conducted across two sessions to maintain children's attention and cooperation. All assessments for each child were completed within a 30-day window. Research staff administered the standardized assessments to the child in a child-friendly assessment room. Interviews with parents were completed either at the laboratory or via telephone, depending on the preference of the family.

The protocol for the experimental session was developed initially to test whether measures of attention to nonsocial stimuli versus CDS stimuli would predict later language outcomes in a longitudinal study of the ASD sample (Watson et al., 2010). To that end, the stimuli were created to be ecologically valid, and thus were complex, multimodal stimuli involving both visual and auditory components. In addition, the protocol was administered in a standard order in the original study to avoid confounding the predictor variables with order effects in the longitudinal analyses. Thus, for the present study, the typically developing children were exposed to the stimuli in the same, standardized order. A standard resting condition (participant sitting quietly without focal stimuli) was not included due to the poor feasibility of participant compliance, as reported in work with typically developing children (Calkins & Dedmon, 2000) and children with developmental disabilities (Roberts et al., 2001) in this age range. In the present study, however, neither the nonsocial nor the CDS condition required a specific response; the stimuli were simply presented in the participants' visual field.

For the experimental session, two surface electrodes were placed on the child's chest and attached via leads to a small Mini-Logger transmitter unit, which was then placed in the child's pocket or a waist pack. The IBIs of the child's heartbeat were detected by the electrodes and transmitted to a receiver. A research assistant activated a marker switch connected to the receiver to record the beginning and end of each condition or vignette during the session.

The child was seated in a high chair positioned three feet from the center of a puppet theater, which contained a window through which stimuli were presented. The child's parent sat in a chair next to the child. A small video camera mounted just above the theater window recorded the child's behavioral responses, and provided a clear image of the child's face and eyes when he oriented toward the theater window. All experimental sessions were completed between 9 a.m. and 12 p.m. to control for the effect of circadian rhythm on heart activity.

Videos of the experimental session were coded using Noldus Observer 3.0 software (Software for Behavioral Research, 1996) to measure sustained looking at the stimulus window. The coding of videotapes for sustained looking began once coders reached a training reliability standard of at least 80% agreement. Reliability coding was completed on five randomly selected sessions (23%), with a mean interrater agreement of 88% and a mean kappa of .75.

Heart activity was synchronized with the experimental sessions by aligning the markers inserted into the heart activity data with the videotaped data. Heart activity was edited using MxEdit software (Delta Biometrics, Bethesda, MD). For any condition, if the amount of heart activity data requiring editing exceeded 20%, data were excluded from analyses. RSA was calculated using MxEdit consistent with the procedures developed by Porges (1985). RSA was quantified during each sequential 30-second epoch, and averages were computed for each condition. For the three CDS vignettes, RSA was computed for each vignette and the resulting values were averaged to derive the mean RSA during CDS. Some data were missing due to: (a) technical problems during physiological data collection (no useable data for two children in the ASD group, one in the TLA group, and one in the TCA group); (b) excessive artifacts in physiological data (no useable data for two children in the ASD group and three children in the TLA group, and no useable data for the nonsocial condition for one child in the TLA group and two children in the TCA group); and (c) technical problems with videorecording of behavioral data (no useable data for one or more conditions/CDS vignettes for one child in each group).

Data analysis

To test the hypotheses related to sustained attention and IBI, groups were compared across the different stimuli using a MANOVA. The statistic reported for these analyses is Pillai's Trace, due to its robustness for analyses involving small sample sizes, unequal size groups, and violations of assumptions (Tabachnick & Fidell, 2007). If the omnibus test for the MANOVA was significant, the univariate tests were examined for the main effect of group, and post-hoc group comparisons were made using the Games-Howell test for multiple comparisons. The Games-Howell test is designed for unequal variances, which were present in our data, and also takes into account unequal group sizes (Jaccard, Becker & Wood, 1984). The hypotheses related to RSA were examined using a repeated measures ANOVA, to examine the hypothesized interaction between group and stimulus type (nonsocial versus CDS). Data were analyzed using SPSS 19.0.

Results

Descriptive data on the children's performance on the measures used in the data analyses are provided in Table 2. Physiological data are provided for children in the TLA group as well, although this group was excluded from analyses of physiological measures.

Due to the amount of missing physiological data, we considered the possibility that results might be biased by patterns of missing data. We examined where children with missing physiological data fell within their respective groups on the variables of chronological age, MSEL Early Learning Composite (i.e., total standard score), PLS Expressive Communication age equivalent scores, and mean proportion of sustained looking during the CDS condition. These variables were selected due to their significant levels of correlations with one or more physiological variables for either the ASD or the TCA group. Specifically, for the TCA group, chronological age correlated significantly with IBI during sustained looking in both the nonsocial condition, $rho(11) = .667$, $p = .03$, and the CDS condition, $rho(12) = .604$, $p = .04$. For the ASD group, the MSEL Early Learning Composite correlated significantly with mean RSA during the CDS condition, $rho(18) = .504$, $p = .03$; the PLS Expressive Communication age equivalent scores correlated significantly with RSA during the nonsocial condition, $rho(18) = .482$, $p = .04$; and the proportion of sustained looking during the CDS condition correlated significantly with mean RSA during the CDS condition, $rho(18) = .498$, $p = .04$. Based on this visual analysis of outliers, children with missing data did not present any clear patterns that might bias the study outcomes. Participants with missing data were deleted on a case-by-case basis in each analysis.

Group Comparisons of Behavioral Responses to Nonsocial and to CDS Stimuli

We first used a MANOVA to compare the three groups on sustained looking at nonsocial and CDS stimuli. The Box's test of equality of covariance matrices was non-significant, but Levene's test of equality of error variance indicated a significant difference in error variance for sustained looking at CDS. The multivariate result was significant for group, Pillai's Trace = .594, $F = 9.50$, $df = (4, 90)$, $p < .001$, partial eta squared = .297. The univariate tests of main effects indicated significant effects for both sustained looking at nonsocial stimuli, $F = 11.03$, $p < .001$, partial eta squared = .329, and sustained looking at CDS stimuli, $F = 8.31$, $p = .001$, partial eta squared = .270. In post-hoc comparisons between groups for nonsocial stimuli, the ASD and TCA groups did not differ from one another, $p = .256$, but both looked a larger proportion of the time than the TLA group, $p < .001$, 95% CI .076, .432; and $p < .001$, 95% CI .151, .519, respectively. For CDS stimuli, the ASD and TLA groups did not differ from one another ($p = .447$), but both looked a smaller proportion of the time than the TCA group, $p < .001$, 95% CI −.496, −.141; and $p = .001$, CI −.371, −.091, respectively. The comparisons of groups are displayed graphically in Figure 1. Our results for this planned analysis partially supported our first hypothesis in that children with ASD performed like the TCA group in sustaining attention to nonsocial stimuli, but showed less sustained attention to CDS. They did not, however, look less overall to CDS stimuli than the TLA group.

Visual inspection of the data suggested a more complex pattern of group differences in responses to the three CDS vignettes, however. Thus, as an exploratory analysis, we ran second MANOVA to examine the differences among the three groups in proportion of looking at CDS when the three different CDS vignettes (i.e., video story, live puppet show, and video nonsense toy) were separated rather than aggregated. The multivariate effect for group was significant, Pillai’s Trace = .576, $F = 6.06$, $df = (6, 90)$, $p < .001$, partial eta squared = .288. Examining the univariate main effects, we found that the main effect for group was significant for each CDS vignette: Video Story, $F = 8.68$, $p = .001$, partial eta squared = .27; Puppet Show, $F = 8.4$, $p = .001$, partial eta squared = .269; Video Toy, $F = 5.94$, $p = .005$, partial eta squared = .205. Due to a significant Levene’s test for each of the three CDS vignette, the Games-Howell test was used in the post-hoc group comparisons. The ASD and TLA groups did not differ in proportion of looking for either Video Story or Video Toy, but the ASD group looked significantly less than the TLA group during the live Puppet Show, $p = .004$, 95% CI −.406, −.072. The ASD group looked a smaller proportion of the time than the TCA group during Video Story, $p = .001$, 95% CI −.541, −.136. The TLA group also looked a smaller proportion of the time than the TCA group during Video Story ($p < .001$, 95% CI −.639, −.218), but did not differ significantly from the TCA group in proportion of looking during Puppet Show ($p =.766$) or Video Toy ($p = .058$). Figure 2 shows the proportions of looking for the three groups of children during the different CDS vignettes. As illustrated in this figure, variability in the post-hoc comparisons is accounted for by an increase in the proportion of sustained looking by the TLA group during the Puppet Show compared to the videotaped CDS vignettes, rather than by a decrease in the proportion of sustained looking during the Puppet Show for children with ASD.

Although the use of proportions potentially can change the distributional patterns of the data, the proportional data in this study had the same general distributional properties as the raw data due to the reasonable consistency in length of conditions across children. Alternative analyses in which seconds of looking were prorated to a standard viewing time of 60 seconds for each condition yielded the same pattern of findings with comparable statistical values. Also, analyses using a censored linear regression model to examine influences of potential ceiling effects in sustained looking for children in the TCA group yielded results consistent with those presented above.

Group Comparisons of Physiological Responses to Nonsocial and CDS Stimuli

The TLA group was omitted from the analyses of physiological responses due to known age-related differences in both IBI and RSA not of interest in these analyses. For the analysis examining IBI, the Box’s test of equality of covariance matrices was significant, and the Levene’s test of equality of error variances indicated that the two groups differed in error variance for both the nonsocial and CDS stimuli. The omnibus test showed a significant multivariate effect for group, Pillai’s Trace = .263, $F = 4.64$, $df = (2, 26)$, $p = .$

019, η_p^2= .263. The univariate models indicated significant main effects for group for both nonsocial stimuli (F = 4.34, p = .047, η_p^2 = .138) and CDS stimuli (F = 8.56, p = .007, η_p^2 = .241). For each type of stimuli, the ASD group had smaller IBIs (i.e., faster heart rates) than the TCA group (see Table 2 for values).

For the repeated measures ANOVA examining RSA during nonsocial and CDS stimuli, the Box's test for equality of covariance matrices and the Levene's test for equality of error variances were nonsignificant, suggesting that the model assumptions were met. The analysis showed no significant effect for group (F = 1.29, p = .265, η_p^2 = .046), stimulus type (Pillai's Trace = .065, F = 1.88, p = .182, η_p^2 = .065), or the group x stimulus type interaction (Pillai's Trace = .045, F = 1.32, p = .261, η_p^2 = .046). The direction of the nonsignificant group differences, as shown in Table 2, was for the ASD group to show lower RSA than the TCA group, and for the ASD group to show more decline in RSA from nonsocial to CDS stimuli than the TCA group. Following recommendations of Onwuegbuzie and Leech (2004), we examined the observed power associated with these nonsignificant results and found it to be at low levels of .195 for group, .262 for stimulus type, and .198 for the group x stimulus type interaction.

Discussion

The first aim of the current study was to examine the extent to which children with ASD and typically developing comparison groups would demonstrate similar responses to nonsocial versus CDS stimuli in proportion of time spent looking. Consistent with previous investigations (Klin, 1991; Kuhl, et al., 2005; Paul et al., 2007), children with ASD demonstrated diminished attention to CDS compared to typically developing peers at the same chronological ages. They differed from typically developing peers of comparable language age, however, only in the amount of attention to the live CDS vignette, and not to the videotaped CDS vignettes. This effect was not attributable to *decreased* attention among children with ASD to live versus videotaped CDS, but rather to *increased* attention to live versus videotaped CDS in the TLA group. Order effects do not explain the findings, given that the live CDS vignette was inserted between two videotaped CDS vignettes, both of which elicited less sustained looking from the TLA group. Our findings are consistent with those of Kuhl and colleagues (Kuhl, Tsao & Liu, 2003), who reported that 9-month-old typically developing infants did not demonstrate phonetic learning from videotaped exposure to CDS, but did so in the context of live, interactive exposure to CDS. The findings from this exploratory analysis raise the possibility that the lack of differences in preferences for CDS reported by Paul et al. (2007) for toddlers with ASD compared to language age-matched peers might be due to the format of stimulus presentation (audiotaped rather than live). Also, our own analyses of sustained attention to the combined CDS vignettes resulted in nonsignificant differences between the ASD and TLA groups, but the exploratory analysis suggests these results would have been different if all the CDS vignettes had been live.

These findings imply possible reduced language learning opportunities for children with ASD. Our data demonstrate the significant impact of live CDS on the sustained attention of typically developing infants and young toddlers just before or concurrent with their initial use of spoken words, and may explain why infants studied by Kuhl et al. (2003) learned aspects of language from live CDS but not from videotaped CDS. We can only speculate, however, whether children with ASD would fail to show the same learning advantages from exposure to live CDS compared to videotaped CDS. Given the clinically observed propensity of some children with ASD for learning scripted language from television, this would be a valuable comparison to make in future research. Results of video modeling studies have suggested that video presentation actually may promote better learning than live presentation for at least some skills among children with ASD (Charlop-Christy, Le &

Freeman, 2000), but language learning from video modeling has not been well-studied. Our own findings suggest that children with ASD sustained attention equally well to live versus video CDS. However, if children with ASD only attend to live CDS about two-thirds as much of the time as typically developing children at comparable language ages, then the children with ASD have diminished opportunities for language learning. Decreased opportunities resulting from inattention of children with ASD could impact language acquisition even though their caregivers may be providing as much CDS as parents of typically developing children, and may be equally synchronous with their children's focus of attention (Siller & Sigman, 2002; Watson, 1998). Intervention implications are that CDS exposure may need to be intensified for children with ASD, or that the properties of CDS that successfully engage the attention of children with ASD must be identified and maximized during interactions.

A second aim of the present study was to compare physiological responses of children with ASD to those of chronological age-matched typically developing children during exposure to nonsocial and CDS stimuli. The ASD group demonstrated shorter IBIs than their chronological age-matched peers, a finding that was nonspecific to stimulus type. This suggests that their autonomic system functioning differs for their chronological age, possibly implying a less mature system, or specific endogenous factors likely interacting with environmental conditions. Our finding is consistent with several previous studies that have reported higher heart rates for children with ASD compared to their peers (e.g., Bal et al., 2010; Goodwin et al., 2006; Kootz & Cohen, 1981) but contrary to several other studies with older children and adolescents that failed to find heart rate differences (Graveling & Brooke, 1978; Hutt et al., 1975; Lake et al., 1977).

One unique feature of the IBI data examined in this study is that it reflected IBI only for time periods during which children were looking at the nonsocial or CDS stimuli, that is, the mean IBI during periods of sustained attention. Thus, the fact that children with ASD in this sample had lower mean IBIs (i.e., increased heart rate) during the experimental conditions than children in the TCA group probably cannot be attributed to the fact that they spent less time looking at the stimuli. The finding of a decreased mean IBI, even during periods of sustained looking at stimuli, is consistent with an interpretation that children with ASD may have overactive sympathetic systems or underactive parasympathetic systems, or both. However, our findings related to RSA do not support an explanation resting on an underactive parasympathetic system in our participants (although we cannot completely rule out that possibility, as we will discuss below). In addition, our data do not suggest that children with ASD experience disproportional arousal when attending to social versus nonsocial stimuli, in contrast to the research by Dalton and colleagues (2005), but are more consistent with the possibility that at least some children with ASD have overall high levels of sympathetic activity, as suggested by Hirstein et al. (2001).

The two groups did not demonstrate differences in RSA during nonsocial or CDS stimuli. Overall RSA differences between ASD children and their peers were hypothesized, based on previous studies of children with ASD (Althaus et al., 2004; Ming et al., 2005; Toichi & Kamio, 2003; Vaughan Van Hecke et al., 2009); however, the participants in those investigations were older, and the procedures and stimuli investigated in the studies varied from the current investigation. Our analyses also failed to yield the expected interaction effect between group and stimulus type, which would have suggested that attention to CDS stimuli is more effortful and/or less positive than attention to nonsocial stimuli for children with ASD. Methodological limitations in the present study may account for the lack of expected results. In particular, there were a relatively small number of children with RSA data in each group, and RSA was computed over relatively brief time periods, which may have contributed some instability to the RSA measurement. As reported in the results section, our RSA analysis had low observed power to detect effects. The absolute differences in RSA were in the hypothesized directions. Taken together, these factors dictate a cautious interpretation of our results; that is, an adequately powered study using the current protocol might replicate previous findings of lower RSA in children with autism compared to their peers. One potential application of the RSA results of the current study would be to use our data to estimate effect sizes for a priori power analyses in future investigations.

There are other potential explanations for our pattern of results that heart period and not RSA was significantly different in the ASD group. Possibly the group differences reflect developmental changes that are unique to ASD, reflecting either a delay or deviance in maturation of the autonomic nervous system. Alternatively, differences in RSA may emerge later in development, given that these differences have been reported in older-aged children with ASD (Bal et al., 2010; Van Hecke et al., 2009). Preliminary data in infants (aged 8 to 40 months) with fragile X syndrome supports this hypothesis, in that the relationship of heart period to autistic symptoms emerged earlier than the relationship of RSA to autistic symptoms, 9 months versus 22 months respectively (Roberts, McDonald, Kelleher & Shinkareva, 2010). Because our current sample was so young (29 to 42 months), and RSA and IBI are still maturing at least through the first 2 years (Alkon et al., 2006; Calkins & Keane, 2004), our findings may reflect both maturation and atypical development. Very little work has examined individual stability and developmental change in autonomic measures in typically developing children (Alkon et al., 2006; Calkins & Keane, 2004), and no previously published studies of which we are aware report heart activity in children with idiopathic autism under 5 years of age; thus, these hypotheses need to be tested in future research.

Limitations

The current study is limited in several respects. First, as noted above, observed power was limited and especially low in the analysis of RSA. A second challenge to an unambiguous interpretation of our results is the nature of the stimuli presented. In our original investigation (Watson et al., 2010), we aimed to determine the predictive value of within-group variability in behavioral and physiological responses to CDS for social-communication outcomes for young children with ASD; for that reason, we sought to use CDS stimuli with high ecological validity. As a result, our stimuli did not represent carefully controlled analogs of nonsocial versus social (CDS) stimuli, child-directed versus adult-directed speech stimuli, or live versus videotaped CDS. Possibly some of our findings may be attributable to uncontrolled factors, such as variability in visual movement across stimuli, or the effects of including a live vignette among our CDS stimuli but not in the nonsocial stimuli.

Another possible influence on IBI and RSA unaccounted for by our methods was motor movements. Porges and colleagues (2007) found that low intensity motor movements did not impact RSA or IBI in school-age children, whereas more intense activity accompanying physical exercise did impact these variables. Based on these findings and the fact that children in the present study were seated in a high chair with a safety belt and thus relatively restrained in their physical activity, motor movements were unlikely to have had a major impact on our findings.

A third limitation of this study is that we selected our sample of children with ASD based on them having expressive language ages less than 24 months; thus, their mean scores were in the lower range of functioning even among young children with ASD. As a result, the findings from this sample may not generalize to young children with ASD functioning at higher language and cognitive levels. Also, the study did not include a comparison group of children with other developmental disabilities matched for CA, cognitive and/or language levels with the children with ASD; therefore, in cases where the ASD group differed from the TLA and/or TCA comparison groups, we cannot eliminate the possibility that the performance of the ASD group was due to a more general aspect of developmental disability (e.g., cognitive impairment) rather than specifically to ASD.

Summary and Future Directions

This study replicated previous findings that young children with ASD have diminished attention to CDS, presented either via video or live, in comparison to their typically developing age mates. It adds to the previous literature by suggesting that young children with ASD do not have the same powerful attraction to live CDS as do typically developing children with similar levels of language skills. Physiologically, children with ASD had lower mean IBIs during sustained looking at stimuli than TCA children, suggesting the possibility of at least a mild degree of sympathetic overactivity in our sample that is not specific to social versus nonsocial stimuli. Difficulty in modulating arousal levels conceivably could be associated with less efficient processing or adaptation. Over 100 years ago, Yerkes and Dodson (1908) proposed that performance had a curvilinear association with arousal, with arousal in a moderate range being optimal for best performance. Further, they proposed that the difficulty of a task would shift the optimal range, with a lower optimal arousal range for challenging tasks and a higher optimal arousal range for easy tasks. Recent empirical findings suggest some validity for the model, for instance in finding a negative impact of hyperarousal on perceptual learning of bobwhite quail neonates (Markham et al., 2006), and a positive association of lower baseline heart rates with resilience of adolescents in dealing with life stresses (Oldehinkel et al., 2008). In terms of possible structural mechanisms, Green and Ben-Sasson (2010) cited replicated evidence for amygdala abnormalities among individuals with autism, and suggested that these may play a role in both sensory hyperresponsiveness and anxiety in autism, symptoms associated with autonomic hyperarousal. The interactions among neural circuitry, cardiac responses, and behavioral outcomes are complex and not well-researched, especially in relation to autism. Thus, interpreting the significance of our findings related to apparent hyperarousal among young children with autism remains speculative.

Several findings in this study suggest directions for future research. These include: (a) investigating whether children with ASD learn language differentially from exposure to live versus videotaped CDS; (b) including additional measures of physiological responses to CDS to better understand the role that autonomic regulation may play in the processing of CDS by children with ASD; (c) including a measure of RSA and heart period change or modulation in response to the different CDS vignettes, and (d) including brain imaging measures to add to an understanding of the role that neural structures and circuitry may play in autonomic responses to CDS.

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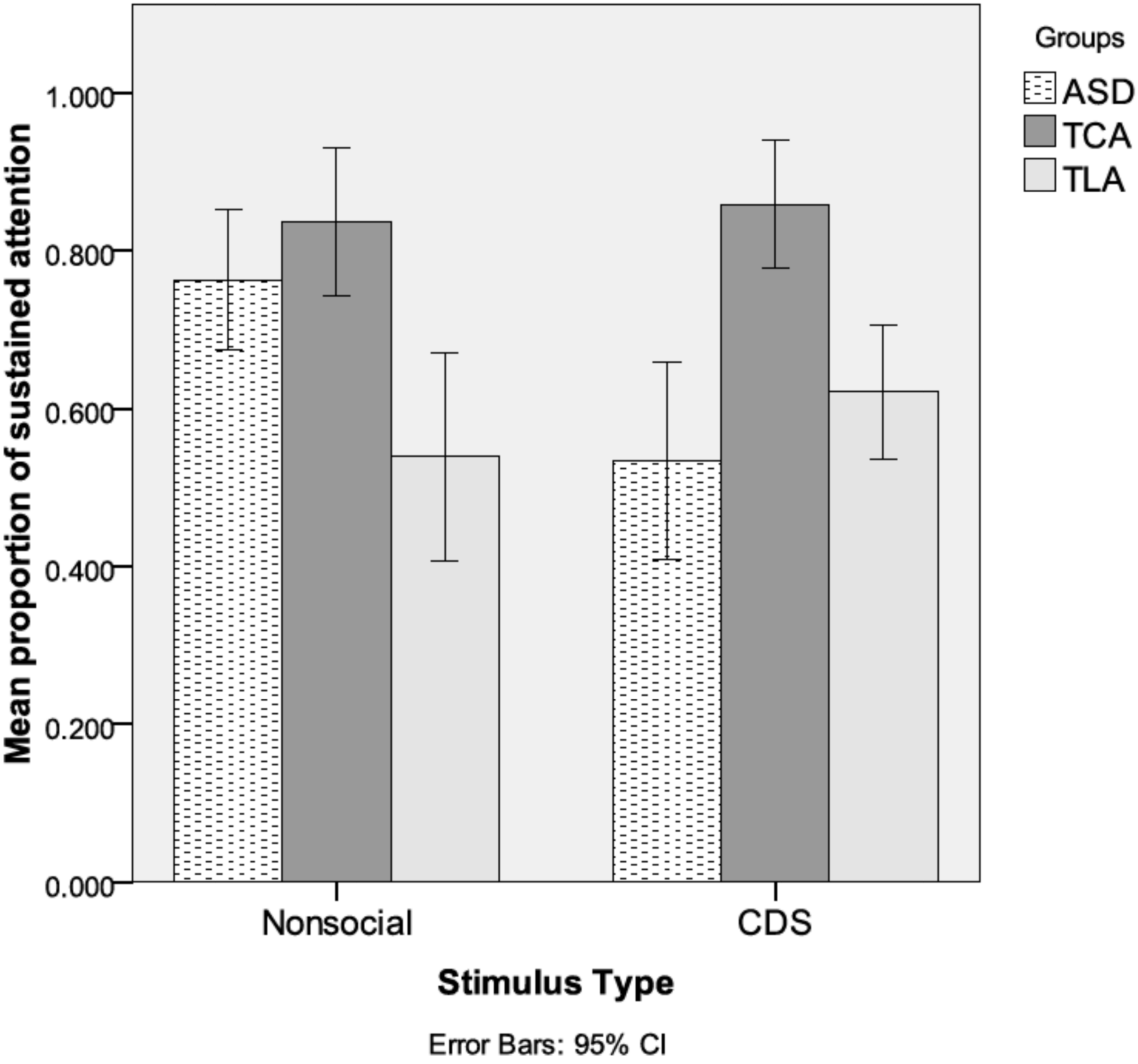

Figure 1.

Proportion of Sustained Attention by Group during Nonsocial and Child-Directed Speech Stimuli

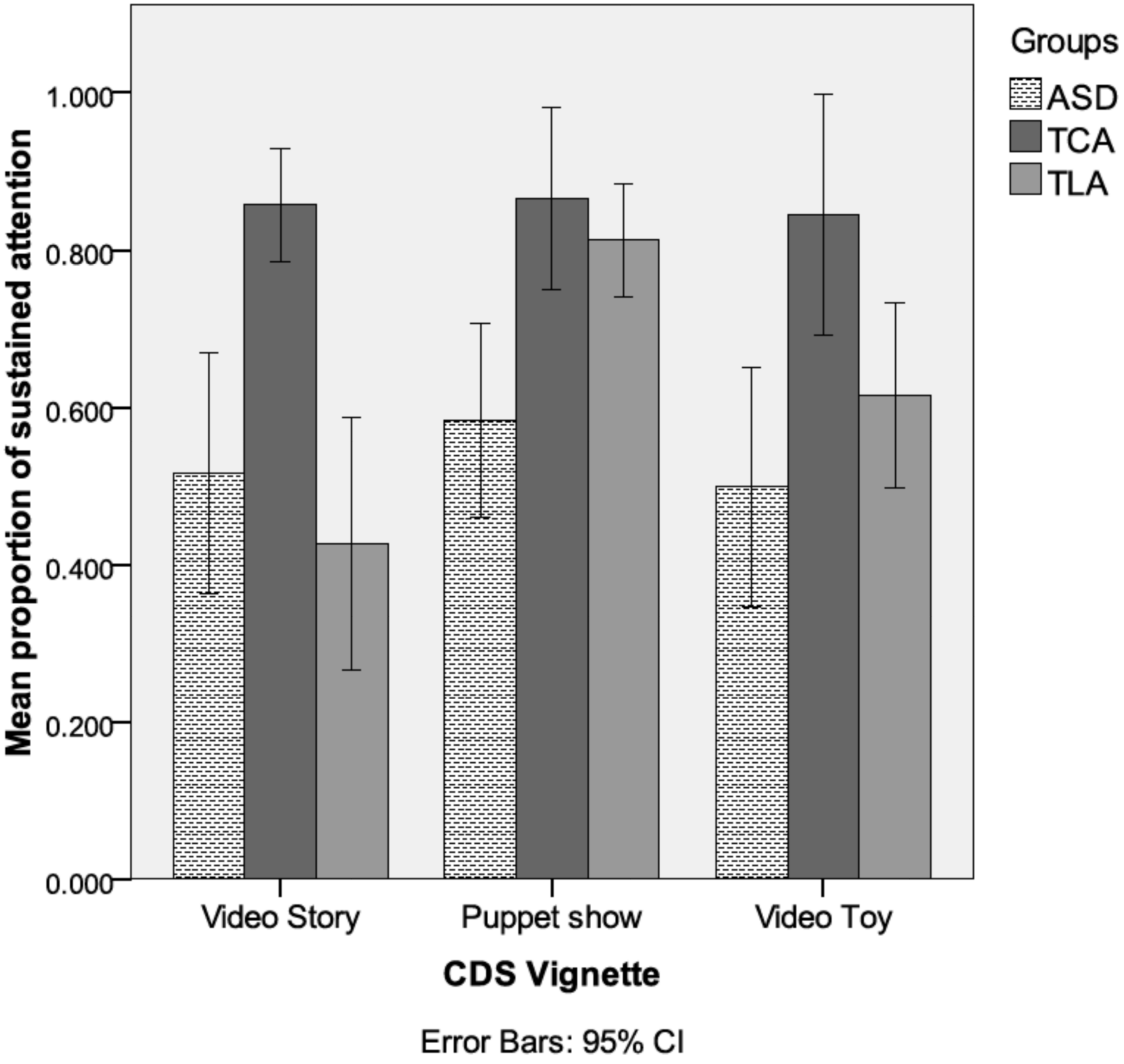

Figure 2.

Proportion of Sustained Attention by Group during Three Child-Directed Speech Vignettes

Table 1

Participant characteristics

	ASD ***N*=22**	**TLA** ***N*=15**	**TCA** ***N*=14**
	M (SD)	*M (SD)*	*M (SD)*
Chronological in months age	35.0 (4.3)[a]	12.9 (3.8)[b]	33.0 (6.1)[a]
PLS-4 [a] Total Standard Score	54.3 (7.5)[a]	105.1 (12.8)[b]	119.6 (10.7)[c]
PLS-4 Expressive Communication Age	13.6 (6.2)[a]	14.5 (4.2)[a]	43.1 (9.2)[b]
PLS-4 Auditory Comprehension Age	11.2 (7.7)[a]	14.7 (4.8)[a]	42.4 (10.7)[b]
MSEL Early Learning Composite	51.1 (3.8)[a]	106.0 (19.8)[b]	116.4 (12.4)[b]
VABS Adaptive Behavior Composite	57.8 (7.0)[a]	106.5 (11.4)[b]	105.9 (15.0)[b]

Note: ASD = autism spectrum disorder; TLA = typically developing, language age-matched; TCA = typically developing, chronological age-matched. PLS-4 = Preschool Language Scale-4th Edition; MSEL = Mullen Scales of Early Learning; VABS = Vineland Adaptive Behavior Scales. In each row, groups with different superscripts differ significantly from one another, $p < .05$; e.g., for chronological age, (ASD = TCA) > TLA.

Table 2

Performance on Sustained Looking and Physiology Measures

	ASD			TLA			TCA		
Measure	***M***	***SD***	***SE***	***M***	***SD***	***SE***	***M***	***SD***	***SE***
Sustained Looking Proportions: Nonsocial Stimuli and Child Directed Speech (CDS)									
Nonsocial	.76	.20	.04	.53	.23	.06	.84	.15	.04
CDS	.53	.28	.06	.62	.15	.04	.86	.13	.04
Video Story	.52	.35	.06	.43	.28	.08	.86	.13	.08
Puppet Show	.58	.28	.05	.82	.12	.06	.87	.19	.06
Nonsense Toy	.50	.34	.06	.62	.22	.08	.85	.27	.08
Inter-beat-interval (IBI) in milliseconds: Nonsocial Stimuli and Child Directed Speech (CDS)									
Nonsocial	512.69	41.67	9.82	495.27	38.79	11.70	565.57	94.51	28.50
CDS	498.10	35.69	8.41	467.49	46.54	13.43	560.25	74.27	21.44
Respiratory Simus Arrhythmia (RSA) : Nonsocial Stimuli and Child Directed Speech (CDS)									
Nonsocial	4.76	1.10	.26	4.56	1.26	.38	4.99	1.19	.36
CDS	4.33	1.04	.24	4.67	1.33	.37	5.29	1.24	.19