



Prosody during tongue twisters in verbally fluent autistic children: Sex differences and correlations with symptom severity

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Abstract

Girls are less likely to be diagnosed with autism spectrum disorder (autism) than boys [1], and may be missed or misdiagnosed due to behavioral characteristics that differ from autistic boys [2]. We investigated sex and diagnostic group differences in the prosodic characteristics of speeded tongue twisters. Sixty-five verbally fluent autistic children and typically developing (TD) children, matched on age, sex ratio, and IQ, were recorded reading the same set of sentences aloud and repeating tongue twisters as quickly as possible. Results showed that the speech rates of autistic girls increased more than autistic boys and TD children during tongue twisters compared to sentences; they also increased pitch more dramatically than TD girls. Correlations between prosody and clinical phenotype revealed that children with greater autism symptoms increased their pitch and speech rate less for speeded tongue twisters than children with milder symptoms. Examined within each sex separately, we found that clinical scores were more strongly correlated with prosody in autistic boys compared to autistic girls. These results suggest that the prosodic characteristics of tongue twisters could index autism symptom severity. Future analyses focused on prosody could shed light on important areas of sex differentiation in verbally fluent autistic children, including flexibility, rule-following, and social motivation.

Index Terms: autism spectrum disorder, pitch, speech rate, tongue twister, sex difference, symptom severity

1. Introduction

Unique characteristics of language and speech were noted in the first descriptions of autism spectrum disorder (ASD) [3] – a neurodevelopmental condition characterized by social communication difficulties and restricted, repetitive behavioral patterns [4]. Research that relies on subjective perceptual judgements of prosody in autistic speech have described it in various and sometimes contrasting ways, including “monotonic” or “sing-song-y” [3][5]. Objective approaches to characterizing autistic speech have revealed distinctive stress patterns [6][7], intonation [8][9], pausing [10], lengthening [11], and loudness [7].

In recent years, a drive to identify reliable speech markers of autism has led to novel approaches that combine objective prosodic measures with subjective prosody perceptions [12][13]. However, many acoustic studies report considerable prosodic variability in autistic speech. This variability leads to inconclusive or discrepant results that reduce the predictive power of these approaches. For example, in contrast to the common misperception that autistic individuals speak with monotonous pitch, acoustic studies have reported larger pitch ranges [14][15] and exaggerated intonation contours [14] in autistic participants compared to typically developing (TD) controls. Similarly, studies of speech rate in autism found that children on the spectrum either articulated slower [16][17] or faster [7] than TD children. It is possible that these discrepant findings emerged due to unaccounted sources of heterogeneity in the autistic group such as age or sex, or because samples were small. Thus, it is critical to consider the possibility that subgroups of children with autism may present with different prosodic phenotypes.

Assigned sex at birth (generally female or male) is one potential source of prosodic heterogeneity that is already known to influence how autism is expressed in a variety of domains. autism is diagnosed more frequently in boys than girls [18], despite comparable autistic traits [19]. However, due to a long history of male-heavy research samples, few studies have had the power to compare autistic boys and girls or autistic girls and TD girls on key social communicative features, including prosody. This is concerning because research conducted on predominantly male samples may not generalize to autistic girls, putting autistic girls at increased risk of systematic underdiagnosis [20]. Recent research shows that autistic girls and boys present distinct symptom profiles in a variety of domains, including social attention [21], social motivation [22], imaginative play [23], gesture [24], and language [2][25][26]. The present study contributes to these research efforts by seeking to clarify whether and how the prosody of autistic girls differs – or does not differ – from autistic boys and TD controls in a structured task.

Previous studies of autistic speech utilized samples drawn from sentence reading tasks, word lists, or semi-structured interviews with an expert clinician. The present study explores prosody during a novel speech elicitation task: tongue twisters.

Tongue twisters have been used to study phonological encoding and speech planning in TD individuals [27] and phonologically-impaired populations [28], as well as in case studies of autistic children's verbal performance [29] or bundled with other tasks as a proxy of oromotor ability [30]. To the author's knowledge, no study to date has quantified the prosodic features of tongue twisters in children with autism, or evaluated potential sex differences associated with this task.

This study aims to inform the field's understanding of atypical prosody in autistic speech. It has been posited that since many individuals with autism have difficulty with executive functioning, including planning, organizing, and inhibitory control, atypical prosody may be related to deficits in "the motor planning and execution aspect of prosodic production" [31]. However, it is also possible that the prosodic differences observed in children with autism are not the same as the patterns observed in individuals with motor planning deficits [32]. By exploring one source of heterogeneity that went unexamined in prior research efforts – sex – we aim to further the goal of identifying a reliable prosodic signature of autism.

2. Research questions

This paper investigates potential sex and diagnostic group differences in the pitch and speech rate of speeded tongue twisters. Our research question is twofold: First, do the pitch and speech rate of speeded tongue twisters differ among autistic girls, autistic boys, typically-developing boys, and typically-developing girls? Second, do the pitch and speech rate of tongue twisters correlate with clinical phenotype in autistic children?

3. Method

3.1. Participants

Sixty-five participants were drawn from research studies conducted at the Children's Hospital of Philadelphia Center for Autism Research. All participants were native English speakers. They included 32 ASD children (15 girls) and 33 TD children (20 girls). Table 1 shows a summary of their demographic information and clinical measures.

Table 1: *Demographic and clinical measures of participants (standard deviations in parentheses). ADOS-2: Autism diagnostic observation schedule-2, SA: Social affect, RRB: Restricted and repetitive behaviors.*

	ASD (n=32)	TD (n=33)	Group difference
Age	11.7 (2.8)	10.9 (2.8)	$t = 1.13, p = 0.26$
Sex (f:m)	15:17	20:13	$\chi^2 = 0.74, p = 0.39$
IQ	108 (10)	109 (12)	$t = -0.27, p = 0.79$
<i>verbal</i>	107	108	$t = -0.39, p = 0.70$
<i>nonverbal</i>	107	106	$t = 0.48, p = 0.63$
ADOS-2 Total	6.53 (2.0)	1.18 (0.4)	$t = 14.98, p < 0.001$
<i>SA</i>	6.63	1.73	$t = 13.46, p < 0.001$
<i>RRB</i>	6.63	1.73	$t = 9.99, p < 0.001$

According to Table 1, the ASD and TD groups were matched on age, full scale IQ estimates [33], verbal and nonverbal IQ estimates, and sex ratio. Diagnoses were confirmed using the Clinical Best Estimate approach [34] with

support from a research-reliable administration of the ADOS-2 Module 3 [35]. ADOS-2 scores comprise two domains: Social Affect (SA) and Restricted and Repetitive Behaviors (RRB), which combine to create the Total score. Independent samples t-tests showed that ADOS-2 Total, SA, and RRB scores significantly differed by diagnostic group (Table 1). Girls and boys with autism were matched on ADOS-2 total scores ($t = 0.005, p = 0.996$).

3.2. Clinical measures

The Social Responsiveness Scale - 2nd Edition (SRS-2) [35] and the Behavior Rating Inventory of Executive Function (BRIEF) [36] were used to estimate autism symptom severity and executive functioning skills, respectively.

The SRS-2 [35] is 65-item rating scale of autism characteristics completed by an adult (parent/caregiver) who is familiar with the child's current behavior and developmental history. In addition to a total score reflecting severity of social deficits in the autism spectrum, the SRS-2 also generates scores for five subscales: restricted and repetitive behaviors, social awareness, social cognition, social communication, and social motivation.

The BRIEF [37] measures everyday behaviors associated with specific domains of executive function. It contains three composite and summary indexes. The *Global Executive Composite* is an overarching summary score that incorporates all of the BRIEF clinical scales. The *Behavioral Regulation Index* captures the child's ability to shift cognitive sets and modulate emotions and behavior via appropriate inhibitory control. It is composed of the inhibit, the shift, and the emotional control scales. The *Metacognition Index* relates directly to a child's ability to actively problem solve in a variety of contexts. It is composed of the initiate, working memory, plan/organize, organization of materials, and monitor scales.

Raw scores from each measure were converted into T scores to provide information about an individual's scores relative to the scores of respondents in the standardization sample. Scores from these measures were correlated with speech features.

3.3. Recording and Annotation

This study was conducted by researchers the Center for Autism Research (CAR) with approval from and oversight by the Institutional Review Board of the Children's Hospital of Philadelphia. Parents provided written informed consent for their children to participate, and children provided verbal assent. Language samples were recorded at home through an automated phone bank at Linguistic Data Consortium (cite). Participants received the following speech instruction: "Now you will see some sentences. Read each sentence out loud and press the green button when you're done." Then they saw each written sentence one at a time:

The girl kicked the ball.

(Say this sentence as fast as you can) Sally sells seashells down by the seashore.

The quick brown fox jumps over the lazy dog.

(Say this sentence as fast as you can) Peter Piper picked a peck of pickled peppers.

The first and third sentences are considered "read sentences" while the second and fourth sentences are considered "speeded tongue twisters" because children were

instructed to say the second and fourth sentences as fast as they could. A team of reliable annotators produced time-aligned, verbatim, orthographic transcripts of audio recordings, with each recording processed by two junior annotators and one senior annotator to produce final transcripts.

3.4. Prosodic features

F_0 values were extracted using *get_f0a* with a 10-ms frame rate and were converted to semitones according to Eq. (1).

$$\text{Semitone} = 12 * \log_2\left(\frac{F_0}{F_{0_base}}\right) \quad (1)$$

where the base frequency F_{0_base} was defined as the 5th percentile of all F_0 values of a particular speaker. Speech rate was calculated by dividing the total number of syllables in each sentence by its duration in seconds. For each read sentence and speeded tongue twister, the mean pitch and the mean speech rate were calculated for each speaker. Task differences in pitch and speech rate were then calculated by subtracting the pitch and speech rate of read sentences from those of tongue twisters.

3.5. Statistical methods

Statistical analyses were conducted using the R Statistical environment [38]. Plots were created using *ggplot* [39]. Independent samples t-tests were used to measure group differences in pitch and speech rate. Pearson's correlations measured the associations between children's prosodic characteristics and scores on the ADOS-2, SRS-2, and BRIEF. In two analyses, individuals' mean pitch and speech rate during tongue twisters were represented (1) as raw values, and (2) after subtracting the baseline features of read sentences (to assess task differences).

4. Results

4.1. Prosodic features by task, sex, and diagnosis

Results revealed that all four groups increased their pitch and speech rate during tongue twisters as compared to read sentences, but autistic girls increased their pitch and speech rate to a significantly greater extent than other groups. Figure 1 shows the means and standard errors of the pitch and speech rate of each read sentence and tongue twister for different sex and diagnostic groups.

Independent *t*-tests revealed no significant differences in the raw values of pitch and speech rate of read sentences or

tongue twisters between autistic girls and TD girls or between autistic boys and TD boys. However, significant group differences were found in the *magnitude of increase* in pitch and speech rate during tongue twisters after subtracting the prosodic values of read sentences. The value of autistic girls' speech rate increase during tongue twisters was significantly larger than that of TD girls ($t = 2.68, p = 0.015$), autistic boys ($t = 2.13, p = 0.044$), and TD boys ($t = 2.10, p = 0.045$). Autistic girls' pitch increase was significantly larger than that of TD girls ($t = 2.57, p = 0.020$), but not autistic boys ($t = 0.94, n.s.$) or TD boys ($t = 1.70, n.s.$). No significant differences were found between autistic boys and TD boys in pitch increase ($t = 0.74, n.s.$) or speech rate increase ($t = 0.30, n.s.$), nor between autistic boys and TD girls (pitch increase: $t = 1.71, n.s.$; speech rate increase: $t = 0.55, n.s.$).

4.2. Correlations between prosodic measures and autistic children's symptom severity

Table 2 summarizes significant Pearson's correlations between the prosodic measures of tongue twisters and the clinical phenotype of autistic children as indexed by ADOS-2, SRS-2, and BRIEF scores.

For autistic girls, neither raw pitch nor raw speech rate during tongue twisters was found to correlate with any clinical phenotype measures; pitch increases in the tongue twister task compared to the read sentences task was also not correlated with clinical phenotype. However, task-related speech rate increases were negatively correlated with SRS communication scores ($p = 0.035$) in autistic girls, suggesting that girls who sped up more also had less severe communication challenges as reported by parents.

In contrast, for autistic boys, prosodic measures were correlated with several phenotypic measures. Speech rate during tongue twisters was negatively correlated with SRS total scores ($p = 0.026$), SRS communication scores ($p = 0.045$), SRS restricted and repetitive behavior (RRB) scores ($p = 0.008$), and the BRIEF plan/organize index ($p = 0.026$). In other words, autistic boys with more severe symptoms were slower in tongue twister pronunciation. Finally, pitch increases during the tongue twister task compared to the read sentence task were negatively correlated with autistic boys' BRIEF *Metacognition* Index ($p = 0.002$) and *Global Executive Composite* ($p = 0.036$), and several subscales of BRIEF *Behavioral Regulation* Index (working memory: $p = 0.012$; plan/organize: $p = 0.005$; organization of materials: $p = 0.048$).

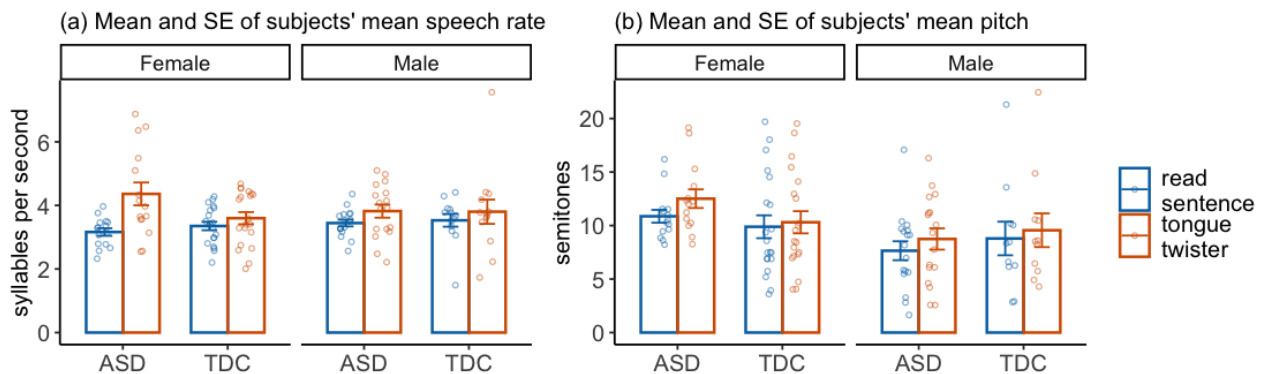


Figure 1. Group comparisons of the mean speech rate and pitch in read sentences and tongue twisters

Table 2. Correlations between prosodic measures of tongue twisters and clinical scores of the SRS-2 and the BRIEF in autistic participants (* $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$)

	Tongue Twister		Tongue Twister Minus Read Sentence	
	pitch (semitone)	speech rate (syllable/second)	pitch (semitone)	speech rate (syllable/second)
Female	n.s.	n.s.	n.s.	SRS communication: $r = -0.59^*$
Male	n.s.	SRS total: $r = -0.59^*$ SRS communication: $r = -0.54^*$ SRS RRB: $r = -0.68^{**}$ BRIEF plan: $r = -0.64^*$	BRIEF executive: $r = -0.61^*$ BRIEF metacog: $r = -0.79^{**}$ BRIEF plan: $r = -0.75^{**}$ BRIEF materials: $r = -0.58^*$ BRIEF memory: $r = -0.70^*$	BRIEF plan: $r = -0.59^*$

5. Discussion

This paper investigated pitch and speech rates in girls and boys with and without autism when reading sentences and producing speeded tongue twisters. Overall, we found a general increase in pitch and speech rate for all children when producing speeded tongue twisters compared to normal (unhurried) sentences. This speech rate increase was expected because participants were instructed to read the tongue twisters as fast as possible, with no such instructions for the normal sentences. Increases in pitch might be due to the additional articulatory and cognitive load associated with the tongue twister task.

In a novel contribution to the literature, our study found both sex and diagnostic group differences in prosody during speeded tongue twisters as compared to read sentences. Specifically, we found that autistic girls increased their speech rates during tongue twisters significantly more than autistic boys and TD children; they also increased their pitch more than TD girls. There are a number of potential explanations for this interesting pattern of results. For example, it is possible that autistic girls followed the written instruction, “Say this sentence as fast as you can” with greater intensity than autistic boys and TD children. This explanation makes sense in light of research showing that some autistic girls are characterized by inflexibility [40], enhanced rule-following [41], or higher social motivation that leads to greater effort in social contexts [22]. These results add to a growing body of research on sex differences in the behavioral characteristics of autistic children. Further research should be conducted to examine the cognitive underpinnings of these differences.

For both autistic boys and girls, our study found negative correlations between prosodic characteristics and autism symptom severity. In other words, children with more severe autistic symptoms were less likely to increase their pitch and/or speech rate when reading tongue twisters vs. normal sentences (i.e., less likely to change their behavior in response to directions). These correlations were primarily exhibited by autistic boys, which is consistent with our group comparison results demonstrating that autistic girls articulated tongue twisters fastest among all groups. For autistic girls, the speech rate increase in tongue twisters was found to negatively correlate with their SRS communication scores, suggesting their tongue twister performance was also related to their symptom severity. However, because autistic girls strictly followed the instructions to speed up in tongue twister reading, such correlations were less likely to be detected due to their overall high performance.

The results of this study add to our understanding of prosodic variability in verbally fluent autistic children, and

additionally shed light on the question of whether prosody may or may not be associated with challenges in motor planning and execution in ASD. We interpret faster speech rates during tongue twisters as indicating better performance, and higher pitch during tongue twisters as indicating greater articulatory effort (and potentially higher engagement levels). If prosody and motor planning and execution are linked in ASD, then the hypothesized existence of motor planning and execution deficits should lead to worse articulation performance by autistic children compared with TD children during tongue twisters. However, our results do not support this explanation, since group comparisons did not show slower speech rates in autistic children; rather, autistic girls demonstrated the fastest speech rate across groups. Preliminary results from our ongoing study on specific speech errors committed by children during speeded tongue twisters (using the same dataset) shows that verbally fluent autistic children do not make more speech errors during tongue twisters than TD children. Taken together, these findings suggest that verbally autistic children's prosodic differences are unlikely to be caused purely by deficits in motor planning and execution [32]; future research is necessary to understand prosodic differences in children with profound autism or co-occurring language impairments.

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