CAMBRIDGE
UNIVERSITY PRESS

BRIEF RESEARCH REPORT

An acoustic study of lexical stress contrastivity in children with and without autism spectrum disorders

Joanne ARCIULI* and Benjamin BAILEY

Faculty of Health Sciences, University of Sydney
*Corresponding author: Faculty of Health Sciences, The University of Sydney, PO Box 170, Lidcombe 1825, Australia.
*Corresponding author E-mail: joanne.arciuli@sydney.edu.au

Abstract

In this exploratory study, we examined stress contrastivity within real word productions elicited via picture naming in 20 children with autism spectrum disorders (ASD) and 20 typical peers group-wise matched on age and vocabulary. Targets had a dominant pattern of lexical stress beginning with a strong–weak pattern (SW: 'caterpillar', 'butterfly') or a non-dominant pattern of lexical stress beginning with a weak–strong pattern (WS: 'tomato', 'potato'). Children produced each target twice ($n = 320$ productions). Acoustic measures were made for the duration, fundamental frequency, and intensity of the first two vowels for each word production. For vowel duration and fundamental frequency, children with ASD and typical peers produced a similar magnitude of stress contrastivity for SW and WS words. However, there was a significant group difference in the way contrastivity in intensity was realised for WS words whereby children with ASD produced less stress contrastivity than typical peers. Bayesian analyses were in line with our interpretation of our frequentist analyses.

Lexical stress is a type of prosody that is used in languages such as English to contrast strong and weak syllables within polysyllabic words (e.g., a word such as 'zebra' is produced with a strong initial syllable followed by a weak syllable – this pattern is reversed in a word such as 'giraffe'). It has been reported that children with autism spectrum disorders (ASD) have difficulties with perception and production of prosody including lexical stress (see review by Arciuli, 2014). However, speech production studies have seldom utilised acoustic analyses. Judging the magnitude of stress contrastivity by ear is a challenging task, one that is perhaps better accomplished via objective acoustic analyses that enable quantification of stress contrastivity. As far as we are aware, no previous study comparing children with and without ASD has examined the amount of contrast produced across strong and weak syllables within words that begin with different patterns of lexical stress: a strong–weak pattern (SW)

versus a weak–strong pattern (WS). In the current study we explored stress contrastivity in children with ASD versus typically developing (TD) children group-wise matched on age and vocabulary. We used the same methodology reported in recent studies of TD individuals that analysed stress contrastivity acoustically (Arciuli & Ballard, 2017; Arciuli & Colombo, 2016; Ballard, Djaja, Arciuli, James, & van Doorn, 2012).

Acoustic studies of stress contrastivity in typically developing children

The ability to produce stress contrastivity emerges during infancy (Davis, MacNeilage, Matyear, & Powell, 2000). By the time children become toddlers at around two to three years they use contrasting vowel duration across strong and weak syllables in their word productions, although without adult-like intentional control (Kehoe, Stoel-Gammon, & Buder, 1995; Pollock, Brammer, & Hageman, 1993).

There have been only a handful of acoustic studies on the developmental trajectory of children's production of lexical stress, and few have measured the amount of contrast across vowels within adjacent syllables in words/nonwords that have different patterns of lexical stress. Schwartz, Petinou, Goffman, Lazowski, and Cartusciello (1996) analysed the production of two-syllable nonwords by TD children at two years of age. Nonwords were constructed so that there was a SW version as well as a WS version, and these were introduced as labels for novel objects during play. Acoustic analyses of syllable duration, vowel duration, peak intensity, and peak fundamental frequency were undertaken for each nonword production, enabling the calculation of ratios of unstressed to stressed syllables. The results revealed that children produced contrastive stress in both SW and WS contexts, although not in an adult-like manner. Children exhibited a smaller amount of stress contrastivity than adults during their speech production.

Another relative measure of stress contrast is the normalised Pairwise Variability Index (PVI: Low, Grabe, & Nolan, 2000). It is useful beyond its original use in analysing vowel duration, in order to examine stress contrast in terms of intensity and fundamental frequency as well as duration. The normalised PVI was used in an acoustic study by Ballard *et al.* (2012) which reported on stress contrastivity in the word productions of TD children aged three to seven years and adults. A picture naming task included two targets that began with a SW pattern of lexical stress over the initial syllables ('caterpillar' and 'butterfly') and two targets that began with a WS pattern of lexical stress ('potato' and 'tomato'). Results indicated that children use adult-like contrastivity in their production of SW words. By comparison, even when productions were unequivocally rated as correct via perceptual judgements, acoustic analyses revealed that children's stress contrastivity in their production of WS words was not adult-like. Arciuli and Ballard (2017) extended this study by examining production of the same words by eight- to eleven-year-olds. Acoustic analyses revealed that while children of this age are more adult-like in the stress contrastivity they produce in WS words than three- to seven-year-olds, there were still differences in the way stress contrastivity was realised.

Broadly speaking, such findings suggest a protracted developmental trajectory for lexical stress production. Indeed, it has been suggested that speech motor development proceeds over many years, continuing even into early adolescence (Lee, Potamianos, & Narayanan, 1999; Singh & Singh, 2008; Smith, 2006). More specifically, these different trajectories for the production of words beginning with a SW pattern and words beginning with a WS pattern may reflect factors relating to

practice. An initial strong syllable is the dominant pattern for all English words and is the dominant pattern when it comes to nouns (Arciuli & Cupples, 2004, 2006). As a result, English-speaking children have less exposure to WS patterning and have less practice producing it. In addition, producing a WS pattern may be more physiologically demanding for children. Some reasons for this include the possibility that controlling a rising contour may be challenging (Sundberg, 1979). Controlling the production of brief vowels in words with an initial weak syllable may also present challenges (e.g., Allen & Hawkins, 1980, but see Vihman, DePaolis, & Davis, 1998). See DePaolis, Vihman, and Kunnari (2008) for further discussion of such constraints on children's speech production.

The production of stress contrastivity has been examined in languages other than English. For example, Arciuli and Colombo (2016) conducted an acoustic study of Italian-speaking children's productions of trisyllabic words beginning with a SW or a WS pattern over the initial syllables. Results revealed that, unlike English-speaking children, young Italian-speaking children were adult-like in the way they produced stress contrastivity for the majority of trisyllabic WS words. Arciuli and Colombo argued that, as an initial weak syllable is the dominant pattern in trisyllabic Italian words, children have more practice with this pattern, which may enable them to overcome any physiological issues. There are ways to explore the possibility that WS productions may be more challenging than SW productions aside from cross-linguistic studies comparing TD children and healthy adults. One option is to investigate SW and WS productions in children with ASD versus typical peers. Atypical prosody, including atypical lexical stress, has long been reported in ASD.

Acoustic studies of stress contrastivity in children with autism spectrum disorders

As noted in the review by Arciuli (2014), the expressive prosody of individuals with ASD is highly variable, having been described as "monotonic, sing-song-like, robotic, parroted, machine-like, odd, over-exaggerated, and/or stilted" (Järvinen-Pasley, Peppé, King-Smith, & Heaton, 2008, p. 1328). While not all individuals with ASD exhibit atypical prosody, such atypicalities have been reported across the autism spectrum, including in individuals who are high-functioning (Peppé, McCann, Gibbon, O'Hare, & Rutherford 2007; Shriberg, Paul, McSweeny, Klin, Cohen, & Volkmar, 2001). It has been noted that atypical prosody is early appearing (Paul, Fuerst, Ramsay, Chawarska, & Klin, 2011; Wetherby, Woods, Allen, Cleary, Dickinson, & Lord, 2004). Moreover, there have been reports that atypical prosody may persist even after other aspects of speech and language have begun to improve (e.g., DeMyer, Barton, DeMyer, Norton, Allen, & Steele, 1973; Simmons & Baltaxe, 1975). With regard to speech production, in particular, some previous research has found evidence of atypical production of lexical stress in individuals with ASD (Kargas, López, Morris, & Reddy, 2016; McAlpine, Plexico, Plumb, & Cleary, 2014; Paul, Augustyn, Klin, & Volkmar, 2005), while other research has not (Shriberg et al., 2001). None of these studies of lexical stress included acoustic analyses.

A study by Grossman, Bemis, Plesa Skwerer, and Tager-Flusberg (2010) investigated perception and production of prosody in 16 children with ASD versus 15 TD peers. Participants were seven to eighteen years of age. These researchers did utilize acoustic analyses when examining speech production and did use some stimuli that related to lexical stress. However, these stimuli included noun phrases ('a hot DOG') and compound nouns ('HOTdog') and their acoustic measures related to whole words rather

than syllables comprising words/nonwords. As such, the study is not relevant to our focus on the relative change in stress contrast across adjacent syllables. In a study that did report acoustic data on stress contrastivity by measuring individual syllables, Paul, Bianchi, Augustyn, Klin, and Volkmar (2008) elicited utterances using the Tennessee Test of Rhythm and Intonation Patterns (T-TRIP: Koike & Asp, 1981). This test requires participants to imitate prerecorded utterances that utilise sequences of the nonsense syllable /ma/. Participants were 46 individuals with ASD and 20 control participants (age range 7 to 28 years). Paul *et al.* (2008) found modest group differences in terms of acoustic measures of syllable duration (note that they measured the entire syllable rather than focusing only on vowels). Strong syllables were longer than weak syllables but this difference was greater in the TD group by comparison with the ASD group. Van Santen, Prud'Hommeaux, Black, and Mitchell (2010) also explored stress contrastivity via acoustic data. Like Paul *et al.* (2008) they utilised an imitation task, where children repeated two-syllable nonsense words. Participant numbers varied from 23 to 26 TD children (mean age of 6.35) and 24 to 26 children with ASD (mean age of 6.57), depending on the analyses. Results suggested that individuals with ASD may exhibit an atypical balance of acoustic features associated with stress contrastivity.

Van Santen *et al.* (2010) did not offer reasons why children with ASD might produce lexical stress differently from their typical peers. Paul *et al.* (2008) did discuss possible reasons including "underlying difficulty in the perceptual and/or motor apparatus involved in speech production." (p. 120). However, an important consideration in both studies is that nonsense utterances and nonsense words were elicited using imitation. When imitated productions are elicited it is more difficult to separate perceptual and motor influences on participant responding. As such, it is valuable to use non-imitation methods such as picture naming in order to look more closely at speech production that is not immediately preceded by speech perception. Moreover, we were especially interested in comparing stress contrastivity in SW versus WS patterns in children with and without ASD, something which has not been examined in any previous studies that we know of.

The current study

We conducted an acoustic investigation of stress contrastivity in real word productions elicited via picture naming in children with and without ASD. We followed the direction of recent acoustic studies undertaken with TD children that examined stress contrastivity in words with different patterns of lexical stress (words beginning with a SW pattern versus words beginning with a WS pattern). We hypothesised that if children with ASD struggle with stress contrastivity more than their typical peers we might be more likely to see evidence of this in WS productions. As the non-dominant pattern in English there is less opportunity to practise the WS pattern, which may also be associated with unique physiological challenges for children. Production of WS words may reflect speech motor practice/control issues more than the production of SW words.

Method

We used the same four stimuli, the same picture naming elicitation task, and the same acoustic measures employed by Ballard *et al.* (2012) and Arciuli and Ballard (2017) in their studies of TD children. The data reported here are a subset of data collected as part of larger studies.

Participants

Speech production data from 40 Australian English-speaking children were collected. Data collection was approved by the Human Research Ethics Committee at The University of Sydney and written informed consent was obtained from parents of the child participants.

Twenty children had received a diagnosis of ASD (2 females, $M = 88.55$ months) and 20 children were typically developing (2 females, $M = 86.55$ months). The sample of children with ASD were previously described in studies by Bailey, Arciuli, and Stancliffe (2017a, 2017b). These children were recruited from speech pathology and psychology clinics in a large metropolitan area. Before joining our study, children had received a prior clinical diagnosis of ASD, Asperger's syndrome, or pervasive developmental disorder – not otherwise specified using criteria from the Diagnostic and Statistical Manual of Mental Disorders – 4th edition (American Psychiatric Association, 2000). While we did not confirm diagnosis during our study we did collect data on children's adaptive abilities using the Vineland Adaptive Behaviour Scales – 2nd edition (VABS-2; Sparrow, Cicchetti, & Balla, 2005). Consistent with previous research involving children with ASD (e.g., Carter et al., 1998; Perry, Flanagan, Geier, & Freeman, 2009; Volkmar, Sparrow, Goudreau, Cicchetti, Paul, & Cohen, 1987), age-based percentile rank scores for participants in the current study showed considerable deficits in the domain of socialisation ($M = 13.14$, $SD = 23.94$) relative to daily living skills ($M = 23.56$, $SD = 22.66$).

The 20 TD children were drawn from a larger pool of TD children so as to provide a comparison group that was group-wise matched to the ASD group in terms of age and receptive vocabulary (see 'Results').

Test of vocabulary

The Peabody Picture Vocabulary Test – 4th edition (PPVT-4: Dunn & Dunn, 2007) was used to assess receptive vocabulary in order to allow us to group-wise match our children with ASD with TD peers. The test requires participants to select one of four images that corresponds with a target spoken by the researcher.

Stimuli for speech production

Targets were four highly familiar words which were similar in terms of phonological structure over the first two syllables (i.e., CVCV). This enabled easy identification of vowel onsets and offsets for measuring vowel durations. Children viewed a picture of each target and were asked to name it ('butterfly', 'caterpillar', 'tomato', 'potato'). The naming task was performed twice while children were wearing a headset microphone at 10 cm mouth–microphone distance. Speech was recorded using a hand-held recorder (44 kHz sampling rate, 16 bit).

Perceptual and acoustic measures

As described in earlier studies by Ballard et al. (2012) and Arciuli and Ballard (2017), we first determined correct versus incorrect production of the target words. Next, acoustic analysis of only correct productions was made with PRAAT (V5.2.0.1: Boersma & Weenink, 2010). Waveforms and wide band spectrograms (300 Hz bandwidth) were generated for each word production. Acoustic measurements for

the first two vowels of each target were: (1) vowel duration (msec) as measured from onset to offset for the first vowel (V1) and the second vowel (V2), as well as (2) peak vocal intensity (dB), and (3) peak f_0 (Hz) for V1 and V2. These measurements allowed us to calculate PVI values for duration, intensity, and f_0 for each word production. The PVI is the normalised difference between the first two vowels within a word: $PVI\_a = 100 \times \{(a_1-a_2)/[(a_1+a_2)/2]\}$ where a_1 and a_2 are measures of duration, peak intensity, or peak f_0 of the first and second vowels, respectively. A positive PVI indicates first-syllable stress while a negative PVI indicates second-syllable stress. The larger the numerical value of the PVI, be it positive or negative, the greater the level of stress contrastivity.

These PVI values were averaged across the two productions of the same word in order to create six grand PVI values for each child: PVI_ SW_duration, PVI_ SW_intensity, and PVI_ SW_ f_0 (for 'butterfly', 'caterpillar') and PVI_WS_duration, PVI_ WS_intensity, and PVI_ WS_ f_0 (for 'tomato', 'potato').

Results

Descriptive statistics relating to age and receptive vocabulary as measured using raw scores from the PPVT-4 (Dunn & Dunn, 2007) for each group of children are provided in Table 1. As can be seen, independent samples *t*-tests showed no statistically significant differences in age or receptive vocabulary raw scores for children with ASD and TD children. In terms of comparison with the normative data in the test manual, our children with ASD tended to achieve age-based receptive vocabulary percentile rank scores on the PPVT-4 which were lower than the normative average of 50. However, the group mean was still within 1 *SD* of this average ($M = 27.42$, $SD = 24.53$, range = 0.30–79). This is consistent with previous research showing that receptive language, including receptive vocabulary, can be an area of relative weakness for some individuals on the autism spectrum (e.g., Kover, McDuffie, Hagerman, & Abbeduto, 2013).

Perceptual and Acoustic Measures

Of the possible 320 word productions (8 productions for each of 40 children), 29 productions (9.06%) were excluded from acoustic analysis due to error (12.50% of productions from children with ASD and 5.63% of productions from TD peers). Most production errors reflected substitution of phonemes ('calerpillar' for 'caterpillar'). A small number of errors reflected weak syllable deletion (e.g., 'tato' for 'potato'). Table 2 displays these errors.

Table 3 displays the mean PVI values for SW and WS productions. As expected, the PVIs for SW words were generally positive (reflecting first-syllable stress), while the PVIs for WS words were generally negative (reflecting second-syllable stress). Means indicated that for each dependent variable children with ASD produced less stress contrastivity than TD children.

A series of six independent *t*-tests were conducted with a Bonferroni-corrected alpha of .008. The assumption of equal variances was met for all of these tests except for the dependent variable of PVI_WS_intensity, where we reverted to *t*-test results where equal variances was not assumed (see adjusted *df*). Table 4 shows the results of these *t*-tests. All differences between the ASD and TD groups were statistically non-significant with the exception of the test examining PVI_WS_intensity, which indicated that children with

Table 1. Descriptive Statistics for Age and PPVT-4 Scores for ASD And TD Groups

Measure	ASD ($n = 20$)			TD ($n = 20$)			t(38)	p	Cohen's d
	M	SD	Range	M	SD	Range			
Age (months)	88.55	18.69	61–127	86.55	21.34	54–125	0.315	.754	.102
PPVT-4 (raw scores)	96.55	31.21	44–152	109.20	28.23	61–168	1.344	.187	.436

Table 2. Number of Production Errors by Word and Group

Stress pattern	ASD	TD
Strong–Weak		
Butterfly	4	0
Caterpillar	7	4
Weak–Strong		
Tomato	4	1
Potato	5	4

Table 3. Mean PVIs and Standard Deviation for SW Words and WS Words for Both Groups

Measure	ASD ($n = 20$)		TD ($n = 20$)	
	M	SD	M	SD
PVI_SW_D	59.58	31.71	64.77	28.68
PVI_SW_I	3.30	5.05	6.19	3.91
PVI_SW_ f_0	−0.22	5.84	2.99	6.80
PVI_WS_D	−141.82	27.30	−148.37	23.28
PVI_WS_I	−3.34	4.09	−10.65	8.51
PVI_WS_ f_0	−0.65	10.18	5.92	8.73

Notes. PVI: pairwise variability index; SW: strong–weak pattern (BUtterfly, CAterpillar), WS: weak–strong (poTAto, toMAto); D: duration; I: intensity; f_0: fundamental frequency.

Table 4. Results of t-tests for All Dependent Variables

Measure	t-test	BF_{10}
PVI_SW_D	t(37) = 0.537, p = .595, d = 0.178	0.350
PVI_SW_I	t(37) = 2.00, p = .053, d = 0.658	1.457
PVI_SW_ f_0	t(37) = 1.582, p = .122, d = 0.520	0.828
PVI_WS_D	t(38) = 0.817, p = .419, d = 0.265	0.403
PVI_WS_I	t(27.34) = 3.465, p = .002, d = 1.33	24.638
PVI_WS_ f_0	t(37) = 2.159, p = .037, d = 0.709	1.863

ASD produced less stress contrastivity than their TD peers. Bayesian analyses using JASP with default priors (JASP Team, 2018), too, revealed little evidence to support a difference between the groups across these variables with the exception of PVI_WS_intensity, where there was strong evidence of a group difference ($BF_{10} = 24.638$).

Discussion

We conducted an acoustic investigation of stress contrastivity in real word productions elicited via a picture naming task in children with and without ASD. Following recent acoustic studies of TD individuals, we examined stress contrastivity in words with different patterns of lexical stress: words beginning with a SW pattern versus words beginning with a WS pattern. We hypothesised that if children with ASD have more difficulties with stress contrastivity by comparison with typical peers we might be more likely to see evidence of this in their WS productions. For speakers of English, there is less opportunity to practise the non-dominant WS pattern which may be associated with unique physiological challenges for children. Thus, WS word production, in particular, may reflect speech motor control/practice issues more so than the production of SW words when it comes to speakers of English.

The findings provided some support for our hypothesis that there may be subtle acoustic differences in the way that children with and without ASD realise stress contrastivity in their production of WS words but not SW words. Children with ASD tended to produce less contrastivity in their production of WS words by comparison with typical peers. In particular, there was a statistically significant group difference in the amount of stress contrastivity produced in WS words in terms of the relative change in intensity across the initial two syllables, accompanied by a large effect size. We acknowledge debate about whether a Bonferroni adjustment for multiple comparisons might be considered conservative but feel that our approach provides an appropriate consideration of the possibility of Type I and Type II error. Moreover, our Bayesian analyses revealed results that were in line with our interpretation of our frequentist analyses.

Earlier, Paul *et al.* (2008) reported group differences in the way lexical stress is produced in individuals with and without ASD. They suggested that participant-related perceptual and/or motor issues might be at play. Unlike Paul *et al.*, who used imitation to elicit responses, we used the non-imitation method of picture naming. This enabled us to look at speech production without the immediate influence of speech perception on the part of the participant. The fact that a group difference in production emerged during picture naming in the current study suggests that motor issues might be responsible. Indeed, there is a separate body of research suggesting that (at least some) children with ASD experience motor issues relating to gross, fine, and speech motor control (e.g., Adams, 1998; Belmonte, Saxena-Chandhok, Cherian, Muneer, George, & Karanth, 2013; Gernsbacher, Sauer, Geye, Schweigert, & Hill Goldsmith, 2008).

While speech motor issues in (some) children with ASD may relate to impaired execution or difficulties with planning and sequencing movements, it is also possible that (some) children with ASD may lack the social motivation to sound like others (i.e., lack of 'tuning up' as described in the discussion by Paul *et al.*, 2008). The fact that the subtle group differences in stress contrastivity we observed only emerged in the production of WS words suggests that speech motor control/practice issues may be a more likely explanation than lack of motivation to tune-up to others' speech. Presumably, a lack of motivation to tune-up to others' speech would affect both SW and WS words. However, we only found a statistically significant group difference in the production of WS words.

The non-dominant WS pattern of stress is less common than the dominant SW pattern in English. Thus, children may have less practice with the non-dominant WS pattern. Although speculative, it is possible that this lack of practice might interact with speech motor issues in a way that affects those with ASD more than their TD peers. An interesting question is why our acoustic analyses of stress contrastivity in WS words showed a statistically significant group difference only in terms of intensity. Our study cannot answer this question, but this might be a worthy avenue to pursue in future research. It would also be valuable for future studies to include a wider range of SW and WS words when exploring the ideas we have proposed here.[1] We wish to emphasise that our study only examines one specific aspect of speech production, production of lexical stress, using a particular index of contrastivity. It is possible that the speech of those with ASD differs from that of TD peers in other ways.

The findings we report here have implications for research relying only on perceptual judgements of speech production. Like the earlier studies by Ballard et al. (2012), Arciuli and Ballard (2017), and Arciuli and Colombo (2016), our findings suggest that, even when word productions are correct via perceptual judgements, there can be fine-grained acoustic differences in the way stress contrastivity is realised. In addition, our findings suggest that these subtle acoustic differences may interact with the stress pattern of target words. Thus, it is valuable to consider multiple stress patterns in order to obtain a reliable estimate of performance across production of different word types.

Conclusion

In this study of how stress contrastivity is realised during speech production, we elicited 320 word productions from children with and without ASD via picture naming. The key finding of the current study is that there are fine-grained acoustic differences in the way that children with ASD produce stress contrastivity by comparison with typical peers. The fact that these subtle differences emerge in the production of WS words, but not SW words, suggests that speech motor control/practice issues may be a more likely explanation than a social emulation account whereby children with ASD lack motivation to 'tune-up' to the speech of others around them. This is an exploratory study and additional studies are needed to assess our tentative conclusions. We hope our study spurs further interest in acoustic studies of speech production in children with ASD and TD peers.

References

Adams, L. (1998). Oral-motor and motor-speech characteristics of children with autism. *Focus on Autism and Other Developmental Disabilities*, 13(2), 108–12.

Allen, G., & Hawkins, S. (1980). Phonological rhythm: definition and development. In G. Yeni-Komshian, J. Kavanagh, & C. Ferguson (Eds.), *Child phonology: production* (pp. 227–56). New York: Academic Press.

---

[1]A reviewer noted that our SW and WS stimuli are different in a number of ways and wondered whether this may have affected performance. Table 2 indicates that errors were similar across our SW and WS words. Moreover, the acoustic analyses undertaken here were performed only on correct word productions (i.e., where participants knew the words and were able to pronounce them in an intelligible way). Still, we agree that future studies could strive to select SW and WS items that are more similar.

American Psychiatric Association (2000). *Diagnostic and statistical manual of mental disorders*, 4th ed. Washington, DC: American Psychiatric Association.

Arciuli, J. (2014). Prosody and autism. In J. Arciuli & J. Brock (Eds.), *Communication in autism* (pp. 103–22). Amsterdam: John Benjamins Publishing.

Arciuli, J., & Ballard, K. J. (2017). Still not adult-like: lexical stress contrastivity in word productions of eight- to eleven-year-olds. *Journal of Child Language*, 44(5), 1274–88.

Arciuli, J., & Colombo, L. (2016). An acoustic investigation of the developmental trajectory of lexical stress contrastivity in Italian. *Speech Communication*, 80, 22–33.

Arciuli, J., & Cupples, L. (2004). Effects of stress typicality during spoken word recognition by native and non-native speakers: evidence from onset-gating. *Memory & Cognition*, 32, 21–30.

Arciuli, J., & Cupples, L. (2006). The processing of lexical stress during visual word recognition: typicality effects and orthographic correlates. *Quarterly Journal of Experimental Psychology*, 59, 920–48.

Bailey, B., Arciuli, J., & Stancliffe, R. J. (2017a). Effects of ABRACADABRA literacy instruction on children with autism spectrum disorder. *Journal of Educational Psychology*, 109, 257–68.

Bailey, B., Arciuli, J., & Stancliffe, R. J. (2017b). Effects of ABRACADABRA instruction on spelling in children with autism spectrum disorder. *Scientific Studies of Reading*, 21, 146–64.

Ballard, K. J., Djaja, D., Arciuli, J., James, D. G., & van Doorn, J. (2012). Developmental trajectory for production of prosody: lexical stress contrastivity in children ages 3 to 7 years and in adults. *Journal of Speech, Language, and Hearing Research*, 55, 1822–35.

Belmonte, M. K., Saxena-Chandhok, T., Cherian, R., Muneer, R., George, L., & Karanth, P. (2013). Oral motor deficits in speech-impaired children with autism. *Frontiers in Integrative Neuroscience*, 7. Retrieved from <https://doi.org/10.3389/fnint.2013.00047>.

Boersma, P., & Weenink, D. (2010). PRAAT (Version 5.2.0.1) [Computer software]. Amsterdam: Institute of Phonetic Sciences.

Carter, A. S., Volkmar, F. R., Sparrow, S. S., Wang, J. J., Lord, C., Dawson, G., … & Schopler, E. (1998). The Vineland Adaptive Behavior Scales: supplementary norms for individuals with autism. *Journal of Autism and Developmental Disorders*, 28(4), 287–302.

Davis, B. L., MacNeilage, P. F., Matyear, C. L., & Powell, J. K. (2000). Prosodic correlates of stress in babbling: an acoustical study. *Child Development*, 71, 1258–70.

DeMyer, M. K., Barton, S., DeMyer, W. E., Norton, J. A., Allen, J., & Steele, R. (1973). Prognosis in autism: a follow-up study. *Journal of Autism and Developmental Disorders*, 3(3), 199–246.

DePaolis, R. A., Vihman, M. M. & Kunnari, S. (2008). Prosody in production at the onset of word use: a cross-linguistic study. *Journal of Phonetics*, 36, 406–26.

Dunn, L. M., & Dunn, D. M. (2007). *The Peabody Picture Vocabulary Test*, 4th ed. Minneapolis, MN: Pearson Assessments.

Gernsbacher, M. A., Sauer, E. A., Geye, H. M., Schweigert, E. K., & Hill Goldsmith, H. (2008). Infant and toddler oral- and manual-motor skills predict later speech fluency in autism. *Journal of Child Psychology and Psychiatry*, 49(1), 43–50.

Grossman, R. B., Bemis, R. H., Plesa Skwerer, D., & Tager-Flusberg, H. (2010). Lexical and affective prosody in children with high-functioning autism. *Journal of Speech, Language, and Hearing Research*, 53, 778–93.

Järvinen-Pasley, A., Peppé, S., King-Smith, G., & Heaton, P. (2008). The relationship between form and function level receptive prosodic abilities in autism. *Journal of Autism and Developmental Disorders*, 38(7), 1328–40.

JASP Team (2018). JASP (Version 0.9) [Computer software]. Retrieved from <https://jasp-stats.org/>.

Kargas, N., López, B., Morris, P., & Reddy, V. (2016). Relations among detection of syllable stress, speech abnormalities, and communicative ability in adults with autism spectrum disorders. *Journal of Speech, Language, and Hearing Research*, 59(2), 206–15.

Kehoe, M., Stoel-Gammon, C., & Buder, E. (1995). Acoustic correlates of stress in young children's speech. *Journal of Speech and Hearing Research*, 38, 338–50.

Koike, K. J., & Asp, C. W. (1981). Tennessee test of rhythm and intonation patterns. *Journal of Speech and Hearing Disorders*, 46(1), 81–7.

Kover, S. T., McDuffie, A. S., Hagerman, R. J., & Abbeduto, L. (2013). Receptive vocabulary in boys with autism spectrum disorder: cross-sectional developmental trajectories. *Journal of Autism and Developmental Disorders*, 43(11), 2696–709.

Lee, S., Potamianos, A., & Narayanan, S. (1999). Acoustics of children's speech: developmental changes of temporal and spectral parameters. *Journal of the Acoustical Society of America*, 105, 1455–68.

Low, L. E., Grabe, E., & Nolan, F. (2000). Quantitative characterizations of speech rhythm: syllable-timing in Singapore English. *Language and Speech*, 43, 377–401.

McAlpine, A., Plexico, L. W., Plumb, A. M., & Cleary, J. (2014). Prosody in young verbal children with autism spectrum disorder. *Contemporary Issues in Communication Science & Disorders*, 41, 120–32. Retrieved from <http://www.asha.org/uploadedFiles/ASHA/Publications/cicsd/2014S-Prosody-in-Young-Verbal-Children-With-Autism-Spectrum-Disorder.pdf>.

Paul, R., Augustyn, A., Klin, A., & Volkmar, F. R. (2005). Perception and production of prosody by speakers with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, 35(2), 205–20.

Paul, R., Bianchi, N., Augustyn, A., Klin, A., & Volkmar, F. R. (2008). Production of syllable stress in speakers with autism spectrum disorders. *Research in Autism Spectrum Disorders*, 2(1), 110–24.

Paul, R., Fuerst, Y., Ramsay, G., Chawarska, K., & Klin, A. (2011). Out of the mouths of babes: vocal production in infant siblings of children with ASD. *Journal of Child Psychology and Psychiatry*, 52(5), 588–98.

Peppé, S., McCann, J., Gibbon, F., O'Hare, A., & Rutherford, M. (2007). Receptive and expressive prosodic ability in children with high-functioning autism. *Journal of Speech, Language, and Hearing Research*, 50(4), 1015–28.

Perry, A., Flanagan, H. E., Geier, J. D., & Freeman, N. L. (2009). Brief report: the Vineland Adaptive Behavior Scales in young children with autism spectrum disorders at different cognitive levels. *Journal of Autism and Developmental Disorders*, 39(7), 1066–78.

Pollock, K. E., Brammer, D. M., & Hageman, C. F. (1993). An acoustic analysis of young children's productions of word stress. *Journal of Phonetics*, 21, 183–203.

Schwartz, R., Petinou, K., Goffman, L., Lazowski, G., & Cartusciello, C. (1996). Young children's production of syllable stress: an acoustic analysis. *Journal of the Acoustical Society of America*, 99, 3192–200.

Shriberg, L. D., Paul, R., McSweeny, J. L., Klin, A., Cohen, D. J., & Volkmar, F. R. (2001). Speech and prosody characteristics of adolescents and adults with high-functioning autism and Asperger syndrome. *Journal of Speech, Language, and Hearing Research*, 44(5), 1097–115.

Simmons, J. Q., & Baltaxe, C. (1975). Language patterns of adolescent autistics. *Journal of Autism and Developmental Disorders*, 5(4), 333–51.

Singh, L., & Singh, N. C. (2008). The development of articulatory signatures in children. *Developmental Science*, 11, 467–73.

Smith, A. (2006). Speech motor development: integrating muscles, movements, and linguistic units. *Journal of Communication Disorders*, 39, 331–49.

Sparrow, S. S., Cicchetti, D. V., & Balla, D. A. (2005). *Vineland Adaptive Behavior Scales*, 2nd ed. Circle Pines, MN: AGS Publishing.

Sundberg, J. (1979). Maximum speed of pitch changes in singers and untrained subjects. *Journal of Phonetics*, 7, 71–79.

Van Santen, J. P., Prud'Hommeaux, E. T., Black, L. M., & Mitchell, M. (2010). Computational prosodic markers for autism. *Autism*, 14(3), 215–36.

Vihman, M. M., DePaolis, R. A., & Davis, B. L. (1998). Is there a 'trochaic bias' in early word learning? Evidence from infant production in English and French. *Child Development*, 69(4), 935–49.

Volkmar, F. R., Sparrow, S. S., Goudreau, D., Cicchetti, D. V., Paul, R., & Cohen, D. J. (1987). Social deficits in autism: an operational approach using the Vineland Adaptive Behavior Scales. *Journal of the American Academy of Child & Adolescent Psychiatry*, 26(2), 156–61.

Wetherby, A. M., Woods, J., Allen, L., Cleary, J., Dickinson, H., & Lord, C. (2004). Early indicators of autism spectrum disorders in the second year of life. *Journal of Autism and Developmental Disorders*, 34(5), 473–93.