

Title: Relations among detection of syllable stress, speech abnormalities and communicative ability in adults with autism spectrum disorders.

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Abstract

Purpose: To date the literature on perception of affective, pragmatic and grammatical prosody abilities in autism spectrum disorders (ASD) has been sparse and contradictory. Interestingly, the primary perception of syllable stress within the word structure, which is crucial for all prosody functions, remains relatively unexplored in ASD. Thus, the current study explored syllable stress perception sensitivity and its relation to speech production abnormalities and communicative ability in adults with ASD.

Method: A same-different syllable stress perception task using pairs of identical four-syllable words was delivered to 42 adults with/without high-functioning ASD, matched for age, to investigate primary speech perception ability in ASD. Speech production and communicative ability in ASD was measured using the Autism Diagnostic Observation Schedule.

Results: As predicted, the results showed that adults with ASD were less sensitive in making judgments about syllable stress relative to controls. Also, partial correlations revealed a key association of speech production abnormalities with stress perception sensitivity, rather than communicative ability *per se*.

Conclusions: Our findings provide empirical evidence for deficits on primary syllable stress perception in ASD and its role on socio-communicative difficulties. This information could facilitate the development of effective interventions for speech and language therapy and social communication.

Keywords: Autism Spectrum Disorders; Syllable stress detection; Speech abnormalities; Social communication.

Introduction

Atypical prosody production is one of the most noted deviant characteristics of language in individuals with ASD (for a review see McCann & Peppé, 2003). Despite the overwhelming evidence showing that many individuals with ASD demonstrate atypical prosodic perception skills and atypical-sounding prosody, a speech element that could become a stigmatising barrier to social acceptance (Shriberg, et al., 2001), little is known about the associations of these two abilities (see McCann & Peppé, 2003; O'Connor, 2012 for reviews). Thus, the focus of this paper is first, to explore the relationship between basic speech perceptual skills and speech production abnormalities and second, to explore whether their relationship contributes to the socio-communicative difficulties observed in individuals with high-functioning ASD.

Speech perception has multiple functions. In particular, speech sounds may convey information on the content, the emotional connotation and the identity of the speaker (e.g., Blake & Sekuler, 2006). In linguistics, the term prosody refers to the suprasegmental properties of the speech signal and plays an important role in a range of communicative functions that have been categorized as affective, pragmatic and grammatical (Roach, 2000; Panagos & Prelock, 1997; Shriberg et al., 2001). These functions help the speaker to enhance or change the meaning of what is said (Couper-Kuhlen, 1986; Cruttenden, 1997), hence facilitating communication. Acoustically, prosody is defined by variations in loudness (amplitude), duration, pitch (fundamental frequency), intonation (changes in pitch over time), rhythm (duration, rate and pauses) and stress (the relative prominence of particular units within the speech signal) (Lehiste, 1970; Shriberg, Kwiatkowski & Rasmussen, 1990; Stephens, Nickerson & Rollins, 1983).

Affective prosody refers to changes in the speech register used in different social situations or communicative partners (e.g., speech towards children or work colleagues) and to convey general emotional states (e.g., relaxed or annoyed) (Bolinger, 1989; Hargrove, 1997). Pragmatic prosody refers to different ways an utterance is expressed to deliver the intentions of the speaker and to provide additional social information that goes beyond the syntax of the sentence (e.g., Bates & McWhinney, 1979; Winner 1988). For example, stress can be used pragmatically to emphasize the unit of information within an utterance that requires the receiver's focus of attention. Grammatical prosody is used to indicate whether someone makes a question or a statement and to highlight syntactic information within utterances or sentences (e.g., Gerken, 1996; Warren, 1996). Grammatical stress, for instance, indicates whether a word is a noun (e.g., PREsent) or a verb (e.g., preSENT).

In comparison to prosodic expressive abilities, fewer investigations have explored the processing skills of receptive prosody in individuals with ASD (McCann & Peppé, 2003; O'Connor, 2012; Globerson, Amir, Kishon-Rabin & Golan, 2014). Most of the studies in this area have focused primarily on the perception of pragmatic/affective prosody (Chevallier, Noveck, Happé, & Wilson, 2011; Globerson et al., 2014; Golan, Baron-Cohen, & Hill, 2006; Golan, Baron-Cohen, Hill, & Rutherford, 2007; Grossman, Bemis, Plesa Skwerer, & Tager-Flusberg, 2010; Heikkinen et al., 2010; Järvinen-Pasley, Wallace, Ramus, Happé, & Heaton, 2008b; Jones et al., 2011; Kleinman, Marciano, & Ault, 2001; Lindner & Rosén, 2006; Peppé, McCann, Gibbon, O'Hare & Rutherford, 2007; Rutherford, Baron-Cohen, & Wheelwright, 2002). Several of these studies using complex vocal expressions (i.e. where an understanding of mental states is needed for making a judgment) or complex experimental paradigms (i.e. tasks that demand enhanced cognitive load), reported

findings for atypical perception of pragmatic and affective prosodic cues in individuals with ASD (e.g., Chevallier et al., 2011; Golan et al., 2006, 2007; Kleinman et al., 2001; Rutherford et al., 2002). In contrast, the processing of basic voice expressions and vocalizations (e.g., laughing-happy, crying-sad) appear to be intact in children, adolescents and adults with ASD (Grossman et al., 2010; Heikkinen et al., 2010; Jones et al., 2011), although some studies failed to replicate these findings (Lindner & Rosén, 2006; Mazefsky & Oswald, 2007; Philip et al., 2010).

Research on the perceptual abilities of grammatical prosody in ASD also provides contradictory findings. Specifically, some research groups reported that individuals with ASD exhibited deficits in the comprehension of grammatical cues of word stress (Paul, Augustyn, Klin, & Volkmar, 2005a; Peppé et al., 2007), whereas others have not (Chevallier, Noveck, Happé, & Wilson, 2009; Crossman et al., 2010; Järvinen-Pasley, Peppé, King-Smith, & Heaton, 2008a). A similar pattern of inconsistencies in the results is evident in studies exploring the ability to use stress to perceive phrase structures in individuals with ASD. Specifically, some studies have reported evidence for impaired performance in individuals with ASD relative to controls (Diehl, Benneton, Watson, Gunlogson & McDonough, 2008; Jarvinen-Pasley et al., 2008a), while other studies have not found significant group differences on performance (Paul et al., 2005a; Peppé et al., 2007).

In summary, current research on prosody perception and comprehension in ASD presents a complex picture, characterized by contradictory findings in all areas of prosodic function. Two main potential explanations for these inconsistencies are suggested in the literature. One explanation is that these contradictions are the result of differences among prosodic paradigms (e.g., Diehl et al., 2008; McCann & Peppé, 2003) and the other explanation suggests that previous inconsistencies reflect

heterogeneity in ASD samples (e.g., Jarvinen-Pasley et al., 2008a; McCann & Peppé, 2003). For example, research shows that there is considerable variability in skills found in several domains in people with ASD (e.g., Kargas, López, Reddy, Morris, 2015; Valla & Belmonte, 2013).

Literature on prosody ability in ASD has focused predominantly on prosodic expression, indicating deficiencies in vocal quality that are characterized by inappropriate use of stress (i.e. atypical placement of stress cues within the utterance), pitch variation (i.e. 'robotic or exaggerated intonation), phrasing and rhythm (e.g., Baltaxe, 1984; Baltaxe & Guthrie, 1987; Bonnef, Levanon, Dean-Pardo, Lossos, & Adini, 2011; DePape, Chen, Hall, & Trainor, 2012; Diehl & Paul, 2013; Kujala, Lepistö, & Näätänen, 2013; McCann & Peppé, 2003; Paul et al., 2005a, 2005b; Paul, Bianchi, Augustyn, Klin, & Volkmar 2008; Shriberg et al., 2001). These verbal behaviours are present at infancy and highly persistent with relatively little change over time (Kanner, 1971; Simmons & Baltaxe, 1975). Also, previous findings indicate that the receptive and expressive prosodic deficits are closely related (e.g., Diehl & Paul, 2013; McCann & Peppé, 2003; Paul et al., 2005a; Peppé et al., 2007).

Overall, pragmatic, affective and grammatical stress perception and production are suggested to represent an area of particular difficulty for people with ASD (e.g., Diehl & Paul, 2013; Paul et al., 2005a; 2008; Shriberg et al., 2001). However, previous studies on prosody perception in ASD have not investigated primary detection of syllable stress within the word structure independent of meaning. This is important because correct perception of syllable stress is necessary for the development of cognitive reconstructions that link different acoustic versions of an utterance with different affective, pragmatic and grammatical functions and social meaning. Based on previous related findings reporting impaired perception of

pragmatic, affective and grammatical prosody cues in ASD (see McCann & Peppé, 2003; O'Connor, 2012; Kujala et al., 2013 for reviews), it is predicted that the group with ASD would exhibit reduced performance on our syllable stress perception task compared to the comparison group. Deficits in the primary perception of syllable stress could have negative consequences in learning how different acoustic versions of utterances convey different meanings, which in turn could result in atypical receptive and expressive prosodic abilities, communication skills and overall language acquisition (Cutler, Oahan, & van Donselaar, 1997; Mehta & Cutler, 1988; Pierrhumbert, 2003, Wood & Terrell, 1998). In addition, this study aimed to investigate the associations between stress perception and communicative abilities in individuals with ASD. Based on related findings showing a relation between receptive and expressive prosodic skills in higher level experimental tasks (see O'Connor, 2012 for a review), we predicted a similar relation between primary perceptive skills of syllable stress and speech production abnormalities in ASD (e.g., Paul et al., 2005a; Peppé et al., 2007). Finally, it was also hypothesized that both speech perception and production skills would be related to communicative abilities in individuals with ASD (Diehl & Paul, 2013; Paul et al, 2005b).

Methods

Participants

Forty-two native adult English speakers participated in this study. Participants' details are shown in Table 1. The participants were 21 individuals with ASD and 21 typically developing (TD) adults (3 females in each group). Participants with ASD were recruited from the database of the Autism Research Network (ARN, Portsmouth) and through a local adult support group for people with ASD. All participants in the ASD

group had a formal diagnosis of Asperger's Syndrome by experienced clinicians according to the Diagnostic and Statistical Manual of Mental Disorders (DSM-IV; DSM-IV-TR) clinical criteria (American Psychiatric Association (APA), 1994; 2000). In order to confirm their diagnoses and to ensure consistency across participants, the Autism Diagnostic Observation Schedule (ADOS; Lord et al., 2000) was administered. All participants fitted the criteria for ASD. The comparison group was selected through the university's participant pool and local social groups. Ethical approval was provided by the university's Research Ethics Committee. Based on self-reports, it was confirmed that all participants in the comparison group did not have a psychiatric or developmental diagnosis.

All participants completed the Wechsler Abbreviated Scale of Intelligence (WASI; Wechsler, 1999). Verbal IQ (VIQ), performance IQ (PIQ), full-scale IQ (FIQ) and chronological age characteristics of the participants in the ASD and TD group did not differ significantly (all $p > .1$). It is suggested that group-matching designs have a number of methodological limitations, particularly when studying cognitive and language abilities in ASD (Kover & Atwood, 2013; Mervis & Klein-Tasman, 2004), therefore we do not consider our groups equally matched. Thus, in order to be confident that any significant group differences found on syllable stress perception, speech abnormalities and social communication abilities do not reflect differences in intelligence, we also run analyses controlling for VIQ, PIQ and FIQ. Participants received a short hearing test for the standard range of frequencies (250-8000 Hz) using an audiometer. All of the participants had normal auditory acuity, which was a condition for being included in the study.

Syllable stress perception task

A stress perception task was used to test the hypothesis that primary detection of syllable stress will be reduced in the group with ASD. The task was based on 10 four-syllable words with lexical templates that have first syllable stress, such as ‘auditory’ and ‘dandelion’, and 10 four-syllable words with lexical templates that have second syllable stress, such as ‘capacity’ and ‘democracy’. The words were selected from the linguistics databases of MRC Psycholinguistic Database and CELEX. The selection criteria for the words included written and spoken frequency, familiarity and syllable structure. Full details about the selection criteria for the words and the experimental paradigm can be found in Leong and colleagues (Leong, Hämäläinen, Soltész, & Goswami, 2011).

All words were produced by a native female speaker of British English and recorded using Audacity software. Two samples for each word were made, one with stress emphasis on the first syllable position such as *AUditory* (i.e. SUUU) and another one with stress emphasis on the second syllable position such as *auDItory* (i.e. USUU). This factor was labelled as first/second stress position. Generally, in English language stress syllables are louder, longer and higher in pitch than unstressed syllables. The two word samples were matched for total duration and the first two syllables were analysed for mean intensity, fundamental frequency (f_0) and duration using Praat software. The total duration of the two tokens among the word pairs ranged from 800 ms to 1200 ms. Mean values for stressed and unstressed first syllables stress such as *AU* or *au* in *AUditory* and *auDItory* and stressed and unstressed second syllables as for example *di* in *AUditory* and *DI* in *auDItory* are shown in Table 2. Pair samples t-tests were used to confirm that the auditory parameters differed between stressed (S) and unstressed (U) syllables and among words. Word pairs were matched

in all four possible ways (SUUU - SUUU, USUU - USUU, SUUU - USUU, USUU - SUUU), producing two different types of judgments, Same and Different (e.g., Same: *AUditory* – *AUditory* / *auDItory* – *auDItory*; Different: *AUditory* – *auDItory* / *auDItory* – *AUditory*). This factor is referred to as Discrimination type. Therefore, by combining the two factors together, two blocks of 40 trials were created.

Word pairs were presented one after the other (500 ms inter-stimulus-interval) with 2000 ms inter-trial-interval. Participants were requested to make same-different judgments about the position of syllable stress in the pair, (e.g., Same: SUUU - SUUU or Different: SUUU - USUU). Moreover, participants were asked to give their response as accurately and quickly as possible after a question mark appeared on the computer screen (at the end of the second word of each pair). During presentation of the stimuli the computer screen remained blank. Their responses were given by pressing left or right buttons via a computer keyboard with the preferred hand. Finally, the experimenter clarified to the participants that their task was to decide whether the word pairs sound the ‘same or different’ and not whether they were correctly or incorrectly pronounced (Leong et al., 2011). All participants reported that the instructions were clear. Prior to testing participants were given four practice trials and feedback of the accuracy of their responses (text on the screen and verbally) and they did not appear to have any problems executing the task.

Materials

Speech abnormalities and communication skills: The ADOS (Lord et al., 2000) was used to measure speech abnormalities and communication skills in the group with ASD. ADOS Module 4 provides accurate assessment and diagnosis of autism for verbally fluent adolescents and adults suspected of having ASD and is commonly

used by clinicians and in research. An ADOS assessment takes approximately 40 minutes to complete. The ADOS consists of semi-structured situations and standardized activities, which allow the examiner to observe behaviours important to the diagnosis of ASD such as communication, social interaction and play or imaginative use of materials. 'Language and Communication' is one of the five ADOS measures. The ADOS Language and Communication measure assesses the participant's language production skills and style of communication and comprises 10 items. Ratings of item 2 of ADOS Language and Communication score reflect speech abnormalities or in other words atypical vocal characteristics, which are specific to autism. For example, coding involves elements of speech that are unusually slow, rapid, odd-intonation and/or inappropriate stress. Thus, we used the ADOS total scores (excluding item 2) to measure communicative ability and ADOS Language and Communication item 2 as a measure of speech abnormalities in ASD.

Procedure

The study was carried out in a 3 hour testing session. Initially, participants were seen individually by the first and second authors in order to complete the ADOS interview and the intelligence test. After administration of the ADOS and intelligence test, each participant was tested individually on the syllable stress perception task and spoken stimuli were presented via closed cup headphones (HD-3030). Participants were informed that they could terminate their participation at any time and without any negative consequences. Testing took place in a quiet room. Between each experimental procedure rest breaks were given in order to ensure that performance on the tasks was not reduced due to tiredness and fatigue or loss of interest. Finally, all participants reported that they had no problems performing the tasks and they also appeared to be interested and motivated.

Results

Sensitivity and response bias in making judgements about syllable stress were measured using d-prime (d') and criterion (c). Calculated d' and c values as well as mean percentage of correct responses in each condition are shown in Table 3.

Independent sample t -tests revealed significant group differences for sensitivity (d') but not for criterion bias. Specifically, the group with ASD demonstrated significantly lower sensitivity on detecting lexical stress than the TD group task ($t(40) = 2.7, p = .01$). This finding indicates that individuals with high-functioning ASD have difficulties in the detection of acoustic prominence in speech. However, as suggested by the non-significant group difference in the response bias, both groups were equally biased toward giving a same or different response.

A mixed factorial ANOVA, 2 (first/second syllable stress) x 2 (group), using d' as the dependent variable, was conducted to statistically test the effects of varying the syllable template. This revealed a significant main effect of group ($F(1, 40) = 6.9; p = .012$; partial $\eta^2 = .147$) but no significant main effect of first/second syllable stress ($p = .235$) and no significant interaction between group x first/second syllable stress ($p = .114$). The same pattern of results was observed even after controlling for FIQ and VIQ. Overall, the aforementioned results indicate that the participants with ASD made significantly less accurate judgements about shared syllable stress, regardless of the syllable template (i.e. SUUU or USUU).

Due to the heterogeneity of the ASD population and previous findings suggesting considerable variability in performance on acoustic discrimination paradigms (e.g., Jones et al., 2009; Kargas et al., 2015), we further explored the mean scores of d' to assess whether there were concealed subgroups with either

exceptionally good or poor sensitivity performance on stress perception in the ASD group. The criteria for good and poor sensitivity performance were defined correspondingly as 2 *SDs* above and below the mean of the TD group with higher d' indicative of better performance. There were 2 exceptional good performers in each group. However, 7 (33%) individuals in the ASD group had sensitivity values 2 *SDs* below the comparison mean compared to 2 (10.5%) individuals in the TD group. This difference in distribution was significant (χ^2 (df = 2) = 3.53; $p = .038$). All other individuals in both groups performed within 2 *SDs*.

Associations among stress perception, speech production and communication skills in ASD.

In order to explore whether sensitivity in making judgements about shared syllables is associated with the quality of speech production in individuals with ASD, Pearson's correlations were performed between d' average values on performance in the stress perception task and ADOS speech abnormalities scores. These results revealed significant negative correlations ($r = -.75$; $p = .001$) between stress perception and speech abnormalities scores, indicating that lower d' values, that is, less sensitivity on syllable stress, were associated with higher scores in the ADOS speech abnormalities item, or in other words with atypical quality of vocal production. Also, the correlations remained significant even after partialling out all three measures of IQ (VIQ: $r = -.67$; $p = .001$; PIQ: $r = -.66$; $p = .002$; FIQ: $r = -.67$; $p = .002$). However, in contrast to predictions, the correlations between performance on the stress perception task and ADOS Communication total scores were not significant ($r = -.19$; $p = .401$), indicating that impaired sensitivity on stress perception cannot fully account for communication deficits in the group with ASD. Finally, consistent with our hypothesis, there was a moderately large, significant positive correlation between

ADOS speech abnormalities scores and ADOS Communication total scores ($r = -.39$; $p = .028$), indicating that atypical speech production was associated with lower communication skills in ASD. Further, their relationship remained significant even after controlling for VIQ ($r = -.19$; $p = .036$).

To investigate the contribution that sensitivity on syllable stress perception and communicative ability had on speech production abnormalities in ASD, two partial correlations were calculated (see figure 1). First, a partial correlation between ADOS speech production abnormalities scores and performance on the syllable stress perception task, controlling for ADOS Communication total scores. These correlations revealed that the relationship between syllable stress perception sensitivity and quality of speech production remained highly significant ($r = -.68$; $p = .001$) even when controlling for communicative ability. The second partial correlation was between ADOS speech production abnormalities scores and ADOS Communication total scores partialling out performance on the syllable stress perception task. Interestingly, the correlation between communicative ability and speech production abnormalities after partialling out performance on speech perception task was no longer significant ($r = .36$; $p = .110$), although still moderately large. This pattern of results suggests that it is impairments in detecting syllable stress rather than communicative ability *per se* that influence quality of speech in ASD.

Discussion

The principle aim of the present study was to investigate whether the perception of primary syllable stress in the absence of word meaning judgments is intact in individuals with high-functioning ASD. A secondary aim was to explore the relations

among perception of syllable stress, quality of speech production and communicative ability in ASD. Four main findings emerged from the study. First, it was found that the ASD group was significantly less sensitive in the detection of syllable stress relative to controls. Second, even within a relatively homogeneous group with ASD (i.e., autism diagnosis and level of IQ), performance on the syllable stress perception task varied considerably across individuals. Third, correlational analyses revealed that poor perceptual sensitivity of syllable stress was associated with atypical quality of speech production in ASD. Fourth, performance on the stress perception task was not significantly related to communicative ability in ASD, indicating that perceptual difficulties in primary prosodic information cannot fully account for differences in overall language and communication skills. However, it was shown that perception of syllable stress, rather than communicative ability *per se*, influences quality of speech production in ASD.

Our results on the syllable stress perception task adds to previous research reporting impaired receptive abilities across a wide range of prosody functions in ASD (e.g., Chevallier et al., 2011; Diehl et al., 2008; Jarvinen-Pasley et al., 2008a; Paul et al., 2005a; Peppé et al., 2007) and are consistent with previous findings indicating that stress is an area of particular difficulty (e.g., Diehl & Paul, 2013; Paul et al., 2005a; 2005b; 2008; Shriberg et al., 2001). For example, several studies using the Profiling Elements of Prosodic Systems in Children (PEPS-C, Peppé & McCann, 2003), the most widely used standard measure of receptive and expressive prosodic skills in the ASD literature (Peppé, 2009), have concluded that children with ASD have difficulties interpreting pragmatic, affective and grammatical prosodic cues accurately (e.g., Peppé & McCann, 2003; Diehl & Paul, 2013). Our findings extend previous research by showing that adults with ASD appear to have difficulties

detecting syllable stress regardless of whether meaning is important for making the decision.

The prosody impairments in ASD are predominantly thought to stem from either increased attention to perceptual cues of the speech signal (e.g., Mottron, Dawson, Soulières, Hubert, & Burack, 2006), which results in decreased attention to linguistic information (Happé & Frith, 2006), or due to higher-order processing impairments at the level of interpretation, such as understanding mental or affective states of others (e.g., Baron-Cohen, Leslie & Frith, 1985). These explanations postulate that low-level perceptual processes are to a great extent intact in ASD. However, early prosodic deficits have been suggested to be a possible explanation for the later impairments in the comprehension of the pragmatic and socio-emotional meanings and prosody production observed in individuals with ASD (e.g., McCann & Peppé, 2003; Diehl et al., 2008; Diehl & Paul, 2013; Ploog, Banerjee, & Brooks, 2009). For example, correct perception of syllable stress is necessary for the development of cognitive reconstructions that link different acoustic versions of an utterance with different affective, pragmatic and grammatical functions and social meanings. Therefore, the current findings showing that the primary perception of syllable stress is impaired in ASD suggest that basic perceptual acoustic deficits may impact negatively on all prosody functions, at least partly, and consequently might limit the repertoire of higher-order socio-communicative skills.

Another potential explanation for the inconsistencies in previous findings on prosody perception abilities in ASD might lie in the considerable variability in skills that is frequently reported in several domains (Valla & Belmonte, 2013), such as in low-level auditory discrimination ability (e.g., Kargas et al., 2015), language and communication skills (e.g., Kjellmer, Hedvall, Fernell, Gillberg & Norrelgen, 2012),

and sensory behaviours (e.g., Bogdashina, 2003). Autism is a heterogeneous neurodevelopmental condition. Therefore, conceiving of ASD as a homogeneous group of disorders and conceptualizing perceptual abilities and socio-communicative skills as stable over time, seems unjustified and may also lead to contradictory findings (see also Kargas et al., 2015; Mayer, Hannent & Heaton, 2014; Valla & Belmonte, 2013). For example, even within the relatively homogeneous sample in our study (i.e., autism diagnosis and levels of IQ) we found a meaningful subgroup with ASD (33%) (see also Heaton, Williams, Cummins & Happé, 2008; Jones et al., 2009; Kargas et al., 2015) that exhibited markedly poor sensitivity to syllable stress perception (above 2 *SDs* from the control mean) and clear atypical speech.

Interestingly, in the current study performance on perception of syllable stress was associated with speech production abnormalities in ASD, supporting previous evidence showing a correlation between receptive and expressive prosodic skills (e.g., Diehl & Paul, 2013; McCann & Peppé, 2003; Paul, et al., 2005a; 2008; Peppé, et al., 2007). However, it is worth pointing out that perception of syllable stress was not associated with communicative ability in ASD, indicating that factors other than perceptive prosody sensitivities may contribute to the development of communication deficits. Previous studies show that children with ASD do not emulate the speech of their peers like typically developing children do (Baron-Cohen & Staunton, 1994; Paul et al., 2008). For example, their stress production ability is not qualitatively comparable to the level of their peers (Diehl & Paul, 2013; Paul et al., 2005a). This lack of speech emulation is thought to be an important contributing factor to the social communication deficits observed in speakers with ASD (Baron-Cohen & Staunton, 1994; Paul et al., 2008). Receptive prosody precedes and influences the development of expressive prosody. In fact, in typical development, prosody processing ability is

associated with early language acquisition and the development of communication and social skills (e.g., Demuth & Morgan, 1996; Jusczyk, 2003; Pierrehumbert, 2003). Again, the correct perception of the acoustic prominence in speech is necessary for the precise emulation of speech. Therefore, based on our findings we propose the possibility that atypical sensitivity to acoustic cues of speech may influence the development of the speech production in people with ASD. If this suggestion has any kernel of truth, it could facilitate the development of easy to implement and effective interventions for speech and language therapy in ASD (see also Diehl & Paul, 2013; Paul et al., 2005a; 2005b).

On the other hand, previous research has also highlighted that interest in socio-communicative cues plays a crucial role on language acquisition in typically developing infants (e.g., Fernald, 1985; Fernald & Kuhl, 1987). Studies on infants and children with ASD have shown that interest to social cues is significantly less salient relative to typically developing individuals (e.g., Dawson, Meltzoff, Osterling, Rinaldi & Brown, 1998; Klin, 1991). For example, pre-school children with ASD prefer to attend to non-speech stimuli more than to child-directed speech and their cortical mechanisms responsible for speech processing are underdeveloped (Kuhl, Coffey-Corina, Padden & Dawson, 2005; see also Boddaert et al., 2004; Gervais et al., 2004; Lepistö et al., 2005). Therefore, social motivational reasons may also account for the failure to emulate the speech of peers and the speech production abnormalities observed in children with ASD. Thus, at least to some extent, lack of typical social communication and interaction experiences in ASD could have detrimental effects in learning significant linguistic and prosodic features important for effective communication.

Partial correlations revealed a key association of speech abnormalities with stress perception sensitivity, rather than communicative ability *per se* in ASD. This pattern of results is consistent with accounts emphasizing the important role of prosody perception in language acquisition and the development of communication and social skills (e.g., Demuth & Morgan, 1996; Jusczyk, 2003; Pierrehumbert, 2003). These findings indicate that atypical speech perception is the primary contributing factor for speech abnormalities in ASD, such as inappropriate use of stress, which in turn could hinder the development of communication skills. Specifically, we propose that initial atypicalities in the perception of primary acoustic cues in speech may be responsible for speech production abnormalities that contribute to atypical social communication and interaction experiences, which result in the communication deficits observed in ASD. Future research is needed in order to test this hypothesis and to develop adequate theories mapping the development of social communication and interaction skills in ASD.

Previous research shows that adults with developmental dyslexia also have difficulties in the primary detection of syllable stress, which could result in severe phonological deficits (Leong et al., 2010). However, in contrast to people with ASD, individuals with developmental dyslexia do not have difficulties in interpreting pragmatic, affective and emphatic stress cues or in social communication. It is worth pointing out that although our study used the same syllable stress task as in Leong et al. (2010), the acoustic differences of stressed versus unstressed syllables were more differentiated in our task than in the study on developmental dyslexia. In other words, it was easier to make a correct judgement in our task than in the previous study. Yet, by inspecting the percentages of correct responses between the two studies it appears that adults with ASD made more errors than adults with developmental dyslexia while

the control groups in both studies performed similarly (see Leong et al., 2010 for full details). Thus, it is possible that there is a similar but more pervasive basic perceptual prosodic deficit in ASD than in developmental dyslexia, in which different degrees of severity may result in different types of prosodic impairments. We suggest that further research is needed to explore the specificity of these impairments.

It is worth mentioning the limitations for assessing speech abnormalities in ASD in the current study. The ADOS speech abnormalities score is a composite of different types of vocal atypicalities and does not differentiate between subtypes of speech features, thus is not the best measure for speech abnormalities. Therefore, although our principal aim was to explore whether there is an association between syllable stress perception and speech production, we were not able to determine in what way individual differences in sensitivity on primary acoustic cues of syllable stress may impact differentially upon subtypes of speech abnormalities. Furthermore, future studies are needed to assess the extent to which different prosody functions are influenced by individual differences on primary perception of speech. Moreover, future research should attempt to utilize a battery of experimental paradigms in which the linguistic and perceptual dimensions of syllable cues are independently manipulated. Also, more research is needed to understand the role that atypical low-level auditory discrimination abilities in ASD (e.g., O'Connor, 2012; Kargas et al., 2015) play on prosody perception. This information would be of great significance for assisting speech and language therapists to identify particular targets for intervention.

Conclusion

The present study is comprised of two fundamental aspects. First, it provides a direct demonstration for impaired basic perception of acoustic cues for syllable stress within

the word structure, regardless of meaning, in ASD. Second, it provides empirical evidence showing an association between primary detection of syllable stress and speech production atypicalities. However, it is noted that this may relate to high variability of perceptual abilities that is frequently reported in several domains in ASD (e.g., Kargas et al., 2015; Valla & Belmonte, 2013). Furthermore, the current study provides evidence indicating that the relationship between perception of syllable stress and speech abnormalities may contribute to the development of communication deficits observed in ASD. However, it is suggested that perceptual atypicalities cannot fully account for the social communication and interaction impairments in ASD.

Our results support previous reports indicating that studies on basic speech perception could help us to better understand in what way verbal information is processed in individuals with ASD. This information could lead to a better comprehension of the social communication and interaction difficulties individuals with ASD encountered (e.g., Alcántara, Cope, Cope, & Weisblatt, 2012; Diehl & Paul 2013; McCann & Peppé, 2003; Paul et al., 2005b), which could facilitate the development of effective interventions for speech and language therapy and social communication interventions.

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Tables

Table 1. Participants' mean scores and standard deviations (*SD*) for chronological age and IQ scores across groups.

Group		Chronological age	Verbal IQ	Performance IQ	Full IQ
ASD	Mean	30.3	109.8	107.2	109.5
	<i>SD</i>	(10.4)	(18.2)	(15.7)	(18.3)
	Range	35	59	61	59
TD	Mean	29.5	113.9	114.2	115.9
	<i>SD</i>	(11.4)	(9.2)	(10.7)	(10.6)
	Range	42	31	38	32

Table 2. Acoustic parameters of stressed and unstressed syllables (mean across 20 words).

	Stressed	Unstressed	<i>t</i> (19)
First syllable manipulated	E.g. <i>AU</i> in <i>AUditory</i>	E.g. <i>au</i> in <i>AuDItory</i>	
Mean intensity in dB	78.4	69.4	10.0*
(SD)	(2.7)	(4.6)	
Mean <i>f</i> 0 in Hz	222.3	182.8	5.23*
(SD)	(27.0)	(36.3)	
Mean duration in ms	288.2	148.7	6.91*
(SD)	(78.0)	(38.1)	
Second syllable manipulated	E.g. <i>DI</i> in <i>auDItory</i>	E.g. <i>di</i> in <i>AUditory</i>	
Mean intensity in dB	77.1	72.4	5.97*
(SD)	(3.5)	(4.2)	
Mean <i>f</i> 0 in Hz	235.4	182.5	11.6*
(SD)	(19.0)	(22.2)	
Mean duration in ms	236.3	162.4	4.52*
(SD)	(63.3)	(52.9)	

* $p < .001$

Table 3. Mean% correct, d' , c and standard deviations (in parentheses) for performance of both groups in the syllable stress task.

	ASD	TD
First syllable stress (SUUU)		
Same judgement	95.0% (11)	98.5% (2.8)
Different judgement	91.6% (18)	98.1% (2.9)
Second syllable stress (USUU)		
Same judgement	93.3% (7.4)	98.3% (2.8)
Different judgement	90.9% (14)	98.8% (2.1)
d' sensitivity	2.2 (0.7)	2.7 (0.1)
C response bias	0.0 (0.3)	0.0 (0.1)

Figures

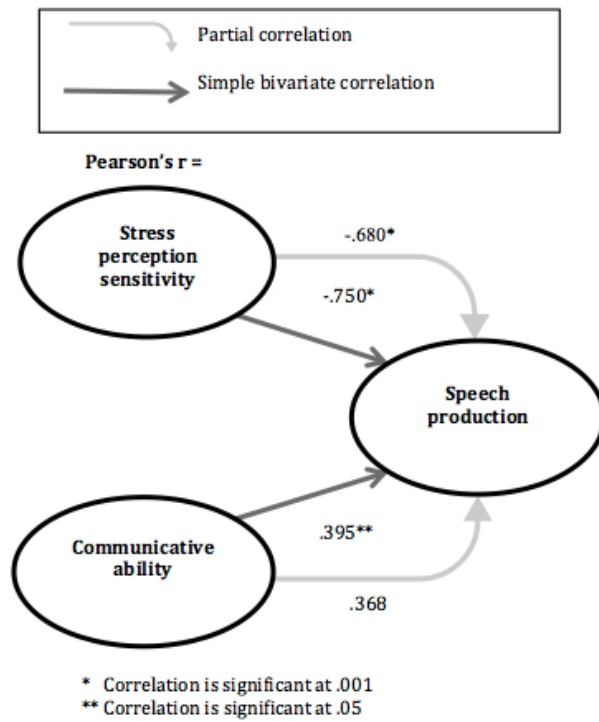


Fig. 1. Illustration of patterns of bivariate and partial Pearson's correlations for syllable stress perception sensitivity and communicative ability associations with speech production atypicalities in ASD.