An Acoustic Investigation of the Developmental Trajectory of Lexical Stress Contrastivity in Italian

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Abstract

We examined whether typically developing Italian children exhibit adult-like stress contrastivity for word productions elicited via a picture naming task (n = 25 children aged 3-5 years and 27 adults). Stimuli were 10 trisyllabic Italian words; half, began with a weak-strong (WS) pattern of lexical stress across the initial 2 syllables, as in *patata*, while the other half began with a strong-weak (SW) pattern, as in *gomito*. Word productions that were identified as correct via perceptual judgements were analysed acoustically. The initial 2 syllables of each correct word production were analysed in terms of the duration, peak intensity, and peak fundamental frequency of the vowels using a relative measure of contrast – the normalised pairwise variability index (PVI). Results across the majority of measures showed that children's stress contrastivity was adult-like. However, the data revealed that children's contrastivity for trisyllabic words beginning with a WS pattern was not adult-like regarding the PVI for vowel duration: children showed less contrastivity than adults. This effect appeared to be driven by differences in word-medial gemination between children and adults. Results are compared with data from a recent acoustic study of stress contrastivity in English speaking children and adults and discussed in relation to language-specific and physiological motor-speech constraints on production.

Keywords: speech; speech production; prosody; lexical stress; acoustic analysis; normalised pairwise variability index; PVI

Introduction

Speech production is a truly remarkable feat. While we have made great progress in understanding the production of individual speech sounds, less is known about the prosodic aspects of speech production. The distinction between strong and weak syllables within single words is a type of prosody known as lexical stress (note that there is no lexical stress in monosyllabic words). For example, in English, *incense* has different meanings depending on whether the pattern of lexical stress is strong-weak (first syllable stress) or weak-strong (second syllable stress). Similarly, the meaning of *ancora* in Italian changes depending on the assignment of lexical stress. Consider the English word *zebra* which has a strong-weak pattern of stress; if one were to produce this word with a weak-strong pattern one may not be understood. This is because stress plays a role in lexical access during spoken word recognition on the part of the listener (see studies of adults by Arciuli & Cupples, 2004, Arciuli & Slowiaczek, 2007, and Cooper, Cutler, & Wales, 2002, as well as studies of infants and children by Curtin, 2010, and Quam & Swingley, 2014). Thus, appropriate production of lexical stress is critical for intelligibility during spoken communication (Field, 2005; Klopfenstein, 2009).

The ability to achieve stress contrastivity during word production is more vulnerable to developmental influences than previously thought. For example, it can be atypical in some individuals with the neurodevelopmental disability of autism (see Arciuli, 2014, for a review). A recent study of English speaking typically developing children aged 3-7 years revealed that even when word productions were identified as correct via perceptual judgements there were fine-grained acoustic differences in the way children realise stress contrastivity in their production of particular words by comparison with adults (Ballard, Djaja, Arciuli, James, & van Doorn, 2012). To date, much of the research on children's production of lexical stress has focussed only on speakers of English (but see DePaolis, Vihman, & Kunnari, 2008, for a cross-linguistic acoustic study of lexical stress in infants exposed to English, Finnish, French

or Welsh at the onset of word use at 10-18 months of age). Questions remain regarding whether *language-specific factors* (such as children's familiarity with certain patterns of lexical stress that are most common in their language) or *physiological constraints* associated with the developing motor-speech system (that may affect words with particular patterns of lexical stress regardless of the language in question), or both, might be at play when children are mastering the production of lexical stress. In the current study, we focussed on speakers of standard Italian, comparing the word productions of typically developing preschool children aged 3-5 years with those of healthy adults, in order to further explore this question.

Measuring Stress Contrastivity

Listeners perceive lexical stress as the distinction between strong and weak syllables within single words. This distinction is realised acoustically in a number of ways and, to a certain extent, depends on the language in question. Even so, the key acoustic correlates of lexical stress relate to the duration, intensity, and fundamental frequency of vowels.

One acoustic measure that can be used to gauge the amount of stress contrastivity across adjacent syllables is the pairwise variability index (PVI). In the literature there are references to the 'raw PVI' and the 'normalised PVI' (different equations are used to derive these values, as explained by Nolan & Asu, 2009). The normalised PVI (where the pairwise difference between syllables is divided by the average value of the pair) is preferable to the raw PVI and far more useful than raw data for individual syllables. This is because both the raw PVI and raw data from individual syllables reflect individual differences amongst speakers. For example, speakers vary in their rate of speech, which is reflected in duration values. Speakers also vary in how loudly they speak which is reflected in intensity values. Finally, speakers vary in terms of the pitch of their voice which is reflected in values for fundamental frequency. In effect, the normalised PVI neutralises these kinds of differences, including any differences which may relate to gender, age, emotional state and so on.

By way of background, the PVI was originally used to examine variability in vowel duration across successive syllables of read sentences in order to understand the rhythmic patterning of different languages (e.g., Grabe & Low, 2002; Low, Grabe, & Nolan, 2000; Tan & Low, 2014). It is one of the so called 'rhythm metrics' that has been useful in exploring the idea that languages are either stress-timed (duration of successive syllables can be uneven) or syllable-timed (duration of successive syllables is even). This idea, originally put forward by Pike (1945) and Abercrombie (1967) was based on perceptual evaluations; many direct investigations of the acoustic signal in the decades since have failed to support a strict dichotomy (e.g., Roach, 1982, Dauer, 1983, and Nespor, 1990, but see Ramus, Nespor & Mehler, 1999). A number of acoustic studies, that have specifically compared English (traditionally described as stress-timed) and Italian (traditionally described as syllable-timed), have indicated that both of these languages exhibit variability in vowel duration across successive syllables although there are differences in the amount of variability (e.g., Braun & Geiselmann, 2011; Mairano & Romano, 2007; Vayra, Fowler, & Avesani, 1987).

Rhythm metrics have uses beyond their original purpose. The normalised PVI has been applied beyond the analysis of vowel duration, to include analysis of the intensity and fundamental frequency of vowels, in order to explore stress contrastivity in the production of English words. For example, Arciuli, Simpson, Vogel and Ballard (2014) used the normalised PVI to provide new insights regarding speech produced in noise by showing that adults do not uniformly increase the intensity of adjacent syllables within words when speaking in noise; rather, they increase the amount of stress contrastivity. Ballard et al. (2012) used the normalised PVI to examine the developmental trajectory of stress contrastivity in the word productions of children versus adults. The methodology of the current study follows the study by Ballard and colleagues, which is described in full in the next section.

Another measure of stress contrastivity is the lexical stress ratio (LSR) which provides a single score per word production (Shriberg et al., 2003). It is a weighted composite of

acoustic data relating to the duration, intensity, and fundamental frequency of vowels in adjacent syllables derived from a principal components analysis. The speech that was used in its formulation was elicited from English speaking children, with either speech delay or suspected apraxia of speech, who produced 8 words with initial syllable stress via an imitation task. The PVI has broader applicability than the LSR because it has been used to measure words with differing stress patterns (not just those with stress on the initial syllable), produced by both typical and atypical speakers. In addition, the normalised PVI can be used to derive separate scores relating to duration, intensity, and fundamental frequency whereas the LSR derives a single score which combines these acoustic measures.

Children's Mastery of Stress Contrastivity

Comparison of child versus adult speech reveals developmental trajectories and can help us understand when children reach 'mastery'. This approach has been used to explore fine-grained acoustic differences in the production of individual segments (e.g., Li, 2012; Nicholson, Munson, Reidy, & Edwards, 2015) and stress contrastivity across adjacent syllables (e.g., Schwartz, Petinou, Goffman, Lazowski, & Cartusciello, 1996; Ballard et al., 2012).

In an acoustic study of young children's production of lexical stress in English Schwartz et al. (1996) examined the production of bisyllabic nonwords by 14 typically developing two year olds via unsolicited imitation. Nonwords were constructed so that there was a trochaic or strong-weak (SW) version as well as an iambic or weak-strong (WS) version. The names of novel objects were introduced by a single adult during play. Analyses of syllable duration, vowel duration, peak intensity and peak fundamental frequency were undertaken. Although raw values for each syllable/vowel were the focus of the analyses, ratios of unstressed to stressed values were also calculated. The results showed that two year olds' productions distinguished between stressed and unstressed syllables in both SW and WS contexts. Although there was only a single adult model, who was using child-directed speech,

the data revealed that children's productions were not adult-like. Across every dependent variable, and for both SW and WS versions of the nonwords, children exhibited less stress contrastivity than adults in their productions. Similarly, Kehoe, Stoel-Gammon, and Buder (1995) conducted an acoustic study of lexical stress in English and found differences in stress contrastivity between children aged 18-30 months and adults. However, that study only examined bisyllabic words with a SW pattern.

A recent investigation of speakers of English used acoustic analyses of word productions to examine the developmental trajectory for stress contrastivity in older children (Ballard et al., 2012). Participants were 73 typically developing children aged 3-7 years and 24 healthy adults aged 20-30 years. The stimuli included 4 words in total. Of these, 2 words had a SW pattern of lexical stress across the initial syllables: *butterfly* and *caterpillar*. The other 2 words had a WS pattern across the initial syllables: *tomato* and *potato*. Productions were elicited via a picture naming task. The adult speech was not child-directed speech. Productions that were identified as correct via perceptual judgements were analysed acoustically. The normalised PVI was used to determine the direction and magnitude of contrastivity exhibited by the vowels within the initial 2 syllables of the polysyllabic words in terms of vowel duration, intensity and fundamental frequency.

The children in the Ballard et al. (2012) study were older than those in the Schwartz et al. (1996) study and as might be expected they did exhibit more adult-like control over stress contrastivity – but not for all word types. Specifically, the results revealed that while contrastivity in words beginning with a SW pattern across the initial syllables appeared to be adult-like, contrastivity in words beginning with a WS pattern across the initial syllables was not adult-like. Generally, for the words beginning with a WS pattern, children showed less contrast than adults in terms of vowel duration and fundamental frequency and more contrast in terms of intensity. It was hypothesised that this finding could reflect language-specific factors relating to first syllable stress being the dominant stress pattern in English (i.e., most

polysyllabic English words begin with a SW pattern). When it comes to words beginning with a weak syllable English speaking children have less exposure to and less practice producing the WS pattern. An alternate hypothesis was that physiological constraints of the maturing motor-speech system might make it more difficult for children to control stress contrastivity when they are producing words that begin with a weak syllable. For instance, as noted by Ballard et al., controlling a rising contour may be more demanding than controlling a falling contour (due to a rise in subglottic pressure: Sundberg, 1979) and controlling production of vowels of brief duration in words with an initial weak syllable may be more difficult (e.g., Allen & Hawkins, 1980, but see Vihman, DePaolis, & Davis, 1998). These kinds of speech production mechanisms are also discussed by DePaolis et al. (2008).

Broad discussion of children's mastery of segmental and suprasegmental aspects of speech production across different languages can also be found in the work of Vihman and colleagues. This body of work focuses on the importance of word learning, in particular, when children are acquiring knowledge of the phonological properties of their language. Multiple constraints are outlined, most of which are related to language-specific factors such as implicit perceptual experience, production practice, and item-specific learning (e.g., Vihman, 2010; Vihman & Croft, 2007).

Lexical Stress in Italian

An obvious way forward in understanding the influence of language specific and physiological motor-speech constraints on the production of stress contrastivity is to increase cross-linguistic research efforts. Standard Italian is a suitable candidate for exploration. Lexical stress is not fixed in either English or Italian. As such, we can examine contrastivity in words with different stress patterns (i.e., words that begin with a weak syllable as well as words that begin with a strong syllable). Moreover, while there are differences in the size of the phonemic inventories of these languages (e.g., Italian has fewer vowels than English), Italian has been described as "not very different from English in terms of the phonetic

challenges it presents to the child" (Keren-Portnoy, Majorano & Vihman, 2009, p. 239). However, it is important to note that there are some differences in phonological structure across these languages. For instance, monosyllabic words are rare in Italian by comparison with English and there are relatively few word initial and word final consonant clusters in Italian by comparison with English.

There are other differences between English and Italian that specifically affect stress contrastivity. For example, English has a tendency for vowel reduction in weak syllables that often results in schwa whereas Italian does not (but see Braun & Geiselmann, 2011). In addition, English distinguishes between long and short vowels in strong syllables whereas Italian does not. These factors mean that syllable duration across successive syllables tends to be more variable in English by comparison with Italian. However, as mentioned above in the section on rhythm metrics, this difference may be thought of as quantitative rather than qualitative. Indeed, acoustic analyses have shown that variability in duration across successive syllables is the key marker of lexical stress in standard Italian (e.g., D'Imperio & Rosenthal, 1999). An earlier perceptual study revealed that contrast in duration is the main cue to lexical stress in Italian (Bertinetto, 1980).

Another difference between the languages concerns geminate consonants, which are present in standard Italian but not English (e.g., *pala* with a single word-medial consonant means 'shovel' but *palla* with a geminate consonant means 'ball' – both words have first syllable stress). While the primary acoustic marker of gemination is lengthening of the consonant, it has been found that for bisyllabic words with stress on the first syllable adult speakers of Italian tend to produce shorter vowels before word-medial geminate consonants than before word-medial singleton consonants (Esposito & Di Benedetto, 1999). There is some evidence that this vowel shortening before geminate consonants also plays a perceptual

role in identifying geminates in Italian (Pickett, Blumstein, & Burton,1999). [1]

Little is known about geminate production in Italian children's speech. Recently, Vihman and Majorano (in press) examined the proportion of words containing geminates in Italian mothers' child directed speech and in their children's speech (children were aged 1-2 years). No acoustic analyses were conducted and the study did not address the question of whether geminates affect the magnitude of lexical stress. We are not aware of any studies that have sought to determine how geminates affect the amount of stress contrastivity in words with different kinds of stress patterns in standard Italian in children or adults (e.g., words beginning with a strong syllable versus words beginning with a weak syllable).

Of particular relevance to the question of language-specific versus physiological motor-speech constraints on children's mastery of stress contrastivity, the dominant patterns of lexical stress in Italian are different from those found in English. Monaghan, Arciuli and Seva (in press) recently examined stress patterns across 6 languages, including English and Italian. Their corpus analysis of English was based on the CELEX database (Baayen et al., 1993), which contains frequency information for 18.6 million words. CELEX includes stress information. Their analysis of stress patterns in Italian was based on the CoLFIS database (Bertinetto, Burani, Laudanna, Marconi, Ratti, Rolando, & Thornton, 2005), which contains frequency information for 3 million words. Stress information is not contained in CoLFIS and was derived from the De Mauro Italian Dictionary (De Mauro, 2000). From each of these corpora, they extracted all bisyllabic and trisyllabic words that had a frequency greater than 0 and identified which syllables carry primary stress. The results confirmed that in English, bisyllabic words are more common than trisyllabic words and first syllable stress is dominant for both bisyllabic and trisyllabic words (85% and 58%, respectively). However, in Italian, bisyllabic words are less common than trisyllabic words and while the majority of bisyllabic

[1] For those interested in the topic of geminates there have been a number of studies that have examined geminates in languages other than Italian (although not an exhaustive list some examples include Abramson, 1999, who examined Pattani Malay; Ridouane, 2007, who examined Tashlhiyt Berber; Idemaru & Guion, 2008, who examined Japanese). Perception and production of geminates may differ across languages.

words have first syllable stress (99%) the majority of trisyllabic words have second syllable stress (81%). These estimates are in line with those obtained from other sources: 80% of words have stress on the penultimate syllable, 18% have stress on the antepenultimate syllable, with only 2% carrying stress on the ultimate syllable (Colombo, 1992; Thornton, Iacobini, & Burani 1997).

If language-specific factors relating to stress dominance influence mastery of stress contrastivity then young Italian children might be adult-like in their production of the dominant pattern of penultimate lexical stress for trisyllabic words – that is, trisyllabic words that have a WS pattern across the initial 2 syllables. Alternatively, if physiological motor-speech control issues associated with words beginning with a weak syllable impact production, Italian children might lack adult-like mastery of stress contrastivity for these words. Thus, data on stress contrastivity in the trisyllabic word productions of Italian children versus adults can assist in exploring these different kinds of developmental constraints on speech production.

Previous Studies of Italian Children's Speech Production

A number of studies have examined the early speech and language abilities of Italian children. Some have done so using the Italian version of the MacArthur-Bates Inventory (e.g., Caselli et al., 1995; D'Odorico, Carubbi, Salerni, & Cavlo, 2001; D'Odorico, Majorano, Fasolo, Salerni, & Suttora, 2011; Rinaldi, Barca, & Burani, 2004; Zmarich, Dispaldro, Rinaldi, & Caselli, 2011), while other studies have used different methods (e.g., Gerosa et al., 2007; Zanobini et al., 2012; Zmarich & Bonifacio, 2005). None of these previous studies included examination of lexical stress.

Bortolini and Leonard (1991) assessed children with a phonological disorder (4-7 years) and typically developing children (2 years of age). Drawings of objects and people were used to elicit word productions. It was reported that 6 of the 9 children with a

phonological disorder and 7 of the 9 typically developing children exhibited weak syllable deletion. The authors stated "Weak syllable deletion (e.g. [galo] for *regalo* [regalo] 'gift') was evident in the speech of a number of the children, owing in part, we presume, to the large number of polysyllabic words in the language." (p. 5). There was no other mention of factors relating to lexical stress. For studies examining weak syllable deletion, amongst other aspects of speech and language, in children with specific language impairment and matched typically developing children see Bortolini and Leonard (2000) and Bortolini et al. (2006).

A recent study of babbling and first words spoken by typically developing children up to the age of 2 years included mention of lexical stress (Majorano & D'Odorico, 2011). During speech elicited via play, 6 of the 11 children produced polysyllabic words, although the actual words produced differed from child to child. These 214 words (83% bisyllabic, 16% trisyllabic, and 1% with four syllables) were analysed in terms of variables such as number of correct consonants. Only the trisyllabic words were analysed in terms of the different stress patterns of the targets. The findings revealed that children were more accurate in their production of trisyllabic words that begin with a strong syllable (e.g., *sedano*) compared to trisyllabic words that begin with a weak syllable (e.g., *patata*) and that they deleted weak syllables less often in the former than in the latter case.

It is not clear why very young Italian children exhibited weak syllable duration in the above mentioned studies. Although prosody is not the only type of information used by infants to determine word boundaries during segmentation of the speech stream, it could be that strong syllables are helpful during speech segmentation by Italian infants, as has been reported in some early studies of English learning infants (e.g., Jusczyk, Cutler & Redanz, 1993; Jusczyk, Houston & Newsome, 1999). This may contribute in some way to greater accuracy for the production of words beginning with strong syllables by very young Italian children. However, as mentioned earlier, the dominant patterns of lexical stress in Italian are different from those found in English. While cross-linguistic research on this topic is lacking,

infants exposed to French Canadian, a language where words don't usually begin with strong syllables, do not use strong syllables as a cue to speech segmentation (Polka & Sundara, 2012, see also Vihman, DePaolis, & Davis, 1998). Moreover, Thiessen and Saffran (2007) showed that even English learning infants can learn to segment speech differently – based on increased exposure to words that do not begin with a strong syllable. We wonder whether the pattern of weak syllable duration reported by Bortolini and Leonard (1991) and Majorano and D'Odorico (2011) might be related to the fact that, due to their chronological age, these very young Italian children were only just beginning to transition from the production of bisyllabic words (most bisyllabic Italian words begin with a strong syllable) to the production of trisyllabic words (most trisyllabic Italian words begin with a weak syllable).

Other studies of Italian have examined production of lexical stress during older, school-aged children's reading aloud of polysyllabic words and nonwords in Italian (e.g., Colombo, Deguchi & Boureux, 2014; Sulpizio & Colombo, 2013). The purpose of these studies was to explore the influence of the dominant pattern of lexical stress as well as the effect of implicit learning of spelling-sound correspondences that serve as cues to stress assignment when reading aloud. The data showed that children had an initial preference to assign stress to nonwords and low frequency words when reading aloud in accordance with the dominant pattern of lexical stress; although, children's sensitivity to spelling-sound correspondences that deviate from the dominant pattern appeared to increase with age as children gained more exposure to print (see Arciuli et al., 2010, for similar work on stress assignment during reading aloud in English).

In summary, the studies that have examined Italian children's production of lexical stress have been concerned with overt errors (e.g., weak syllable deletion) and/or determining which syllable is stressed when children produce a polysyllabic word or nonword. None of these studies has examined the magnitude of stress contrast across adjacent syllables in children's productions and asked whether children's contrastivity is adult-like.

The Current Study

The aim of the current study was different from any of the studies of Italian children's speech production that have been conducted previously. In the present study, following Ballard et al.'s study of English speakers, we examined the developmental trajectory of stress contrastivity in children and adults who speak standard Italian. We sought to address the following question: Is it possible that even when typically developing Italian preschoolers' word productions are perceived to be correct (in terms of both segmental and suprasegmental features) there might be fine-grained acoustic differences in the amount of stress contrastivity they produce when compared with adults? Following Ballard et al. (2012) we utilised the normalised PVI to examine stress contrastivity across adjacent vowels within the initial 2 syllables of trisyllabic words.

Hypothesis 1: We expected that if language-specific factors relating to the dominant stress pattern in Italian influence production then young Italian children would be adult-like in their production of trisyllabic words that have a WS pattern across the initial 2 syllables (e.g., *patata*). This would be unlike the results obtained by Ballard et al. (2012) – English speaking children were not adult-like in their production of the WS pattern.

Hypothesis 2: Alternatively, if there are physiological motor-speech demands associated with the production of words beginning with a weak syllable then young Italian children might not be adult-like in their production of trisyllabic words that have a WS pattern across the initial 2 syllables. This would be similar to the results obtained by Ballard et al.

Hypothesis 3: We hypothesised that a third outcome might also be possible. If both language-specific and physiological influences are at play, and operate in contrasting direction, then young Italian children may be able to overcome (at least some of) the motor-speech control issues associated with the production of words that begin with a weak syllable – because they have more exposure and more production practice with this pattern of stress in

trisyllabic words by comparison with English speaking children. Presumably, this third outcome would be accompanied by the additional finding that Italian children exhibit adult-like production of trisyllabic words that have a SW pattern across the initial 2 syllables, as in Ballard et al.'s study of English speakers.

Studies of adults have shown the importance of vowel duration, in particular, in marking lexical stress in speakers of standard Italian (Bertinetto, 1980; Braun & Geiselmann, 2011; D'Imperio & Rosenthal, 1999; Vayra et al., 1997). Therefore, we expected that the normalised PVI for duration might be a more consistent indicator of whether an Italian word has a SW or a WS pattern by comparison with the normalised PVI for intensity or the normalised PVI for fundamental frequency.

Method

The methodology we used followed that reported in Ballard et al.'s (2012) study of the developmental trajectory of lexical stress production in English speaking children and adults.

Participants

Children living in a small town near Trento, (northern) Italy, were recruited from pre-schools. A total of 27 Italian children took part in the research (20 females and 7 males). Participants ranged in age from 3 to 5 years. There were 6 children aged 3 years (mean = 3.57, SD = .29), 6 children aged 4 years (mean = 4.68, SD = .26), and 15 children aged 5 years (mean = 5.42 years, SD = .28). All had normal hearing acuity, no known developmental, language or genetic diagnosis, and standard Italian as their only language (via teacher report). All were tested individually in a quiet room at their pre-school. Managers of pre-schools gave permission to test onsite. A summary of the research project was provided to the parents of the children. They were required to authorise the evaluation of their children exclusively for scientific aims, and in complete anonymity. Only children whose parents signed the agreement form took part in the study.

A total of 25 adults were recruited from the university community in Padova, (northern) Italy. Adults were all native speakers of standard Italian and ranged in age from 21 to 26 years (mean = 22.2 years, SD = 1.67; 5 males). Adults provided informed consent for participation in the study. All were tested individually in a quiet room in the laboratories at the University of Padova.

Materials and Procedure

Examination of trisyllabic Italian words allowed us to examine the language-specific versus physiological motor-speech constraints on children's speech production that were raised in the study of English by Ballard et al. (2012). As outlined, this is because the dominant pattern of lexical stress in trisyllabic words is different in Italian versus English.

Trisyllabic Italian stimuli were selected with the following constraints in order to maximise the number of correct productions and to facilitate acoustic analysis: (1) all were real words – picturable words of objects that were familiar to young Italian children, (2) all followed the same phonological structure in that the first two vowels being measured were embedded between consonants, (3) all contained consonants that have been found to be in the consonant inventory of Italian children as young as 3 years of age (Zanobini et al., 2012), (4) all of the stimuli had easily demarcated vowel onsets and offsets in the acoustic signal (e.g., no liquids or semivowels) that would facilitate manual acoustic analysis. All of these characteristics applied in the stimuli used by Ballard et al. (2012), except in relation to point (3) where, of course, the inventory of English speaking children were taken into account.

Of the 10 trisyllabic words, 5 begin with a WS pattern of stress across the initial 2 syllables: *patata* (potato), *matita* (pencil), *cucina* (kitchen), *banana* (banana), *tacchino* (turkey). Thus, these words have stress on the penultimate syllable. The other 5 begin with a SW pattern of stress across the initial 2 syllables: *pattino* (skate), *macchina* (car), *gomito* (elbow), *sedano* (celery), *pettine* (comb). Thus, these words have stress on the antepenultimate syllable. Due to the inclusion criteria listed above we were very restricted in

terms of available stimuli. Unfortunately, we were not able to balance the number of items that contained word-medial geminate consonants across the two word types.

As in the study by Ballard et al. (2012) stimuli were presented via powerpoint. A picture of each target was displayed on a laptop and participants were asked to name each of the pictures. The experimenter varied the timing of the powerpoint slides so that participants were speaking using citation form. We did not use carrier sentences because we wanted to avoid any additional prosodic effects due to the position of the target word within a sentence. Participants were given practice items so that they could become accustomed to naming the pictures naturally. There were three different orders of stimuli presentation, counterbalanced across participants. Two presentations of the same pictures, each with a different order, were used for each participant – that is, two productions for each target were collected. A head-mounted microphone with 5 cm distance from mouth to microphone was used in combination with Audacity software on a laptop in order to collect recordings. Responses were sampled at a rate of 48 kHz with 16 bit quantization.

Data Analyses

Both initial perceptual evaluations and acoustic analyses were conducted. It was necessary to conduct preliminary perceptual evaluations in order to determine the correct productions that would be analysed acoustically. Productions were evaluated by two individuals, one of whom had some exposure to Italian but was not a native speaker (a research assistant), and one of whom was a native speaker of Italian (the second author). Productions were evaluated in terms of both the segmental and suprasegmental features of the target.

As in the study by Ballard et al. (2012), acoustic measurements of the initial 2 syllables for correct productions were made with PRAAT software, Version 5.2.0.1 (Boersma & Weenink, 2010). Waveforms and wide-band spectrograms with a 300-Hz bandwidth were generated for each sound file. Vowels were segmented according to visible peaks in the

waveform at which the formant structure was most consistent. For each correct word production, 3 measurements were made for the initial 2 syllables of each word: (1) vowel duration (ms) from onset to offset of glottal pulsing for vowel 1 (V1) and vowel 2 (V2), (2) peak vocal intensity (dB) for the nucleus of V1 and V2, and (3) peak fundamental frequency, f_0 (Hz) for the nucleus of V1 and V2. For the f_0 setting we selected Praat's autocorrelation method optimised for intonation research.

These values are used to calculate separate measures of stress contrastivity: normalised PVIs for duration (PVI_duration), intensity (PVI_intensity), and f_0 (PVI_f_0). The PVI represents the **normalised difference** between the first 2 vowels of each stimulus for each measure: PVI_a = 100 x $\{(a_1-a_2)/[(a_1+a_2)/2]\}$ *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 normalised PVI reflects greater stress on the first syllable, a negative normalised PVI signifies greater stress on the second syllable.

For each participant, normalised PVIs for duration, intensity, and fundamental frequency were averaged across the two productions of each target. Then, for each participant, normalised PVIs were compiled for (1) words beginning with a WS pattern across the initial syllables and (2) words beginning with a SW pattern across the initial syllables. As per Ballard et al. (2012) any grand normalised PVI means that were 2SD from the mean for that condition were replaced with the mean value for that condition (5.6% of child dataset and 2% of adult dataset).

The normalised PVI data was analysed by subjects and by items. For the subject analyses we conducted a series of ANOVAs where age was a non-repeated measure with 4 levels (3 years, 4 years, 5 years, and adults) and there were no covariates. For the item analyses we conducted a series of ANCOVAs where age was treated as a repeated measure with 4 levels (3 years, 4 years, 5 years, and adults) and the word frequency of each item

served as a covariate[2]. Dependent variables that related to trisyllabic words that began with a WS pattern were PVI_ duration_WS, PVI_intensity_WS, and PVI_f_0_WS). In separate analyses dependent variables that related to trisyllabic words that began with a SW pattern were PVI_ duration_SW, PVI_intensity_SW, and PVI_f_0_SW). Unless mentioned, the assumption of equal variances was met for each ANOVA (using Levene's test for the subject analyses) and ANCOVA (using Mauchly's test for the item analyses). Planned contrasts were conducted when a significant main effect of age was observed. All statistical tests were conduced using SPSS.

Results

Child data. In total, we set out to collect 540 word productions (27 participants x 10 targets x 2 productions of each target). A recording failure meant that the second round of productions was not recorded for one of the participants. This left the potential for 530 correct productions.

Perceptual ratings. The raters made perceptual judgements regarding whether each production could be considered to be a correct production in terms of the segmental and suprasegmental features of the target. Where productions varied slightly only in terms of the identity of the final vowel (which were not included in the PVI analyses), but were clearly semantically related to the target, they were considered to be correct (this affected a very small number of productions, for example, a handful of cases of singular/plural cases: pattino/pattini or noun/verb cases: pettine/pettino).

Overall agreement between raters was high at over 90%. Where there was disagreement (this occurred regarding 9 productions) the rating of the native speaker of Italian was chosen. It was found that productions were missing (because the child did not know the

[2] We obtained frequency counts from a corpus of 1,088,725 words from written children's texts, and children's spelling productions (Marconi, Ott, Pesenti, Ratti & Tavella, 1994).

target or, for some reason, chose not to respond) or incorrect (child produced a word that was clearly different from the target) for 15 targets (2.83%). Thus, the accuracy rate was 97.17%.

Adult data. In total, we set out to collect 500 word productions (25 participants x 10 targets x 2 productions of each target). Recording failure meant that the second production for 1/10 words was not recorded for two of the participants. This left the potential for 498 correct productions.

Perceptual ratings. All productions were rated as correct. Thus, the accuracy rate was 100%.

Acoustic measurements of child and adult data.

Means and standard deviations for PVI_duration, PVI_intensity, and PVI_ f_0 for each type of stress pattern, collapsed across all 27 child participants and 25 adult participants, are presented in Table 1 (i.e., these are means from the subject analyses).

– Insert Table 1 here –

As can be seen from the table, in the child dataset the mean PVI_duration was negative for trisyllabic words beginning with a WS pattern (indicating greater stress on second syllable) and positive for trisyllabic words beginning with a SW pattern (indicating greater stress on first syllable). All the other mean PVI values were positive. The mean PVI_intensity was close to zero for trisyllabic words beginning with a WS pattern and was smaller when compared to trisyllabic words beginning with a SW pattern, however, this result was reversed for PVI_f_0. These results suggest that contrast in vowel duration may be the most consistent marker of lexical stress in Italian children's speech production.

Similarly to the child data, in the adult dataset the mean PVI_duration was negative

for trisyllabic words beginning with a WS pattern and positive for trisyllabic words beginning with a SW pattern. All but one of the remaining mean PVI values were positive. In line with the child data these results suggest that the contrast in vowel duration may be the most consistent marker of lexical stress in Italian.

Table 2 displays the mean PVIs for the different word types for children and adults broken down by the age of participants.

– Insert Table 2 here –

Trisyllabic words beginning with a SW pattern

For PVI_duration_SW there was no statistically significant effect of age by subjects (F(3,48) = .825, p = .487, partial-eta-squared = .049) or by items (F(3,9) = .139, p = .934, partial-eta-squared = .044). Similarly, PVI_intensity_SW showed no statistically significant effect of age by subjects (F(3,48) = 1.954, p = .134, partial-eta-squared = .109) or by items (F(3,9) = .668, p = .593, partial-eta-squared = .182). PVI_f_0_SW also showed no statistically significant effect of age by subjects (F(3,48)= .103, p = .958, partial-eta-squared = .006) or by items (F(3,9) = 1.889, p = .202, partial-eta-squared .386).

Trisyllabic words beginning with WS pattern

For PVI_intensity_WS there was no statistically significant effect of age by subjects (F(3,48)= 2.471, p = .073, partial-eta-squared = .134) or by items (F(3,9) = 1.042, p = .420, partial-eta-squared = .258). For the subject analysis Levene's test revealed statistically significant unequal variances across the different age groups so we conducted non parametric tests. The independent samples Kruskal-Wallis test revealed no statistically significant differences in distribution across different age groups (p =.222). Similarly, the independent samples median test revealed no statistically significant differences in the medians across

different age groups (p =.441). Thus, the non parametric tests returned the same result as the ANOVA (retain the null hypothesis). For PVI_f_0_WS there was no statistically significant effect of age by subjects (F(3,48)= .695, p = .559, partial-eta-squared = .042) or by items (F(3,9) = 2.047, p = .178, partial-eta-squared = .406).

For PVI_duration_WS there was a statistically significant effect of age by subjects (F(3,48)= 3.90, p = .014, partial-eta-squared = .196) but not by items (F(3,9) = .717, p = .566, partial-eta-squared = .193). Planned contrasts exploring the significant effect of age for the subject means revealed that the adults' mean was significantly different from the children's overall mean (p = .002, 95% CI for difference: -19.42 and -4.78). There was no significant difference between the mean PVI_duration_WS for 3 year olds versus 4 and 5 year olds combined (p = .80, 95% CI for difference: -10.44 and 13.43) or between the mean PVI_duration_WS for 4 year olds versus 5 year olds (p = .919, 95% CI for difference: -11.54 and 12.78).

As we obtained a significant effect in our subject analysis but not our item analysis for PVI_duration_WS we further explored the data. In particular, we were interested in the effect of a word-medial geminate consonant . There was no geminate in the words *banana, cucina, matita,* and *patata*. However, one word, *tacchino*, did contain a geminate. We conducted separate analyses for the words that did not contain a geminate consonant versus the word that did contain a geminate. Analysis of words without a geminate showed no statistically significant effect of age by subjects (F(3,48) = 2.02, p =.123, partial-eta-squared = .112) or by items (F(3,6) = 1.124, p = .411, partial-eta-squared = .360).

However, analysis of the word with a geminate did show a statistically significant effect of age by subjects (F(3,48) = 4.085, p = .012, partial-eta-squared = .203). Note that it is not possible to conduct an item analysis for a single word. For the subject analysis Levene's test revealed statistically significant unequal variances across the different age groups so we conducted non parametric tests. The independent samples Kruskal-Wallis test revealed a

statistically significant difference in distribution across different age groups (p =.022). Similarly, the independent samples median test revealed a statistically significant difference in the medians across different age groups (p =.013). Thus, the non parametric tests returned the same result as the ANOVA (reject the null hypothesis). Planned contrasts indicated that the adults' mean PVI_duration_WS was significantly different from the children's overall mean PVI_duration_WS (p = .001, 95% CI for difference: -38.12 and -10.14). There was no statistically significant difference between the mean PVI_duration_WS for 3 year olds versus 4 and 5 year olds combined (p = .391, 95% CI for difference: -13.01 and 32.67) or between the mean PVI_duration_WS for 4 year olds versus 5 year olds (p = .391, 95% CI for difference: -13.24 and 33.27).

Table 3 shows the mean PVI_duration_WS (standard deviations in parentheses) for the word *tacchino*, the only one of our WS words that contains a geminate, for children at 3, 4, 5 years and adults. The table indicates that adults exhibit greater contrastivity in terms of vowel duration than children.

– Insert Table 3 here –

Although our subject and item analyses showed no significant differences regarding the normalized PVI for duration of our SW words, a reviewer requested that we conduct separate analyses for the SW words that did not contain a geminate consonant (*gomito, sedano*) versus the SW words that did contain a geminate (*pattini, pettine, macchina*). For words without a geminate there was no statistically significant effect of age by subjects ($F(3,48) = 2.35$, p =.871, partial-eta-squared = .014). For the subject analysis Levene's test revealed statistically significant unequal variances across the different age groups so we conducted non parametric tests. The independent samples Kruskal-Wallis test showed no statistically significant difference in distribution across different age groups (p =.743).

Similarly, the independent samples median test showed no statistically significant difference in the medians across different age groups (p =.289). Thus, the non parametric tests returned the same result as the ANOVA (retain the null hypothesis). Note that it is not possible to conduct analysis by items on 2 items with a covariate of frequency.

Analysis of the SW words that did contain a geminate did not show a statistically significant effect of age by subjects ($F(3,48) = 0.302$, $p = .824$, partial-eta-squared = .019) or by items ($F(3,3) = 0.059$, $p = .978$, partial-eta-squared = .056).

Discussion

Relatively little is known about Italian children's production of lexical stress. Most previous studies that have included mention of lexical stress have focused on overt production errors such as weak syllable deletion (Bortolini et al., 2006; Bortolini & Leonard, 1991, 2000; Majorano & D'Odorico, 2011). In the current study we did not focus on overt errors. Rather, our aim was to address the following question: When typically developing Italian preschoolers' words productions are perceived to be correct are there fine-grained acoustic differences in the magnitude of stress contrastivity they produce when compared with adults?

We used the same methodology as Ballard et al. (2012) who examined the developmental trajectory of stress contrastivity in English speakers. Ballard et al. examined stress contrastivity by analysing the vowels within the initial 2 syllables of trisyllabic English words using the normalised pairwise variability index (PVI). They examined trisyllabic words beginning with a strong-weak pattern (SW), such as *butterfly*, and trisyllabic words beginning with a weak-strong pattern (WS), such as *potato*. They reported that children aged 3-7 years were adult-like in their production of trisyllabic words beginning with a SW pattern but were not adult-like in their production of trisyllabic words beginning with a WS pattern. Ballard et al. hypothesised that these findings could be due to language-specific factors relating to words beginning with a weak syllable exhibiting the non dominant pattern of stress in English or to

physiological motor-speech challenges associated with the production of words beginning with a weak syllable.

In the current study we elicited word productions from typically developing Italian children aged 3-5 years and adults using a picture naming task. Like Ballard et al. we used the normalised PVI to determine the direction and magnitude of stress contrastivity across the initial 2 syllables of trisyllabic words – in terms of vowel duration, peak intensity, and peak fundamental frequency. We developed three possible hypotheses. Our first hypothesis was that if language-specific factors relating to the dominant stress pattern influence stress contrastivity then Italian children would exhibit adult-like production of the trisyllabic words beginning with a WS pattern (unlike English speaking children). Our second hypothesis was that if there are physiological motor-speech challenges associated with producing contrastivity in words beginning with a weak syllable then Italian children might not produce trisyllabic words beginning with a WS pattern in an adult-like manner (similar to the English speaking children). A third hypothesis was that both factors might come into play and effectively 'cancel each other out': Italian children might be able to overcome (at least some of) the physiological challenges of producing trisyllabic words beginning with a WS pattern at an earlier age than English speaking children due to increased exposure and production practice with this pattern of stress (which is dominant for trisyllabic words in Italian but not in English). This third possibility would presumably be accompanied by the additional finding of Italian children achieving adult-like stress contrastivity for trisyllabic words beginning with a SW pattern, as did the English speaking children in the study by Ballard et al.

For the most part our results supported the third hypothesis. For trisyllabic words beginning with a SW pattern Italian children were adult-like in terms of the magnitude of stress contrastivity that they produced (i.e., there were no statistically significant differences between child and adult productions for the participants we assessed and the words included in our assessment). Similarly, for the majority of the trisyllabic words beginning with a WS

pattern Italian children exhibited adult-like mastery of stress contrastivity (i.e., there were no statistically significant differences between child and adult productions for the participants we assessed). Upon closer examination we found that our child participants lacked adult-like mastery of stress contrastivity in their production of one of the trisyllabic words beginning with a WS pattern (*tacchino)*. This item was the only trisyllabic word beginning with a WS pattern that contained a geminate consonant. For this word, children exhibited *less contrastivity* than adults across initial adjacent syllables in terms of vowel duration.

Previous research has shown that adult speakers of standard Italian shorten the length of the vowel preceding a word-medial geminate consonant by comparison with the vowel preceding a word-medial singleton consonant in bisyllabic words (Esposito & Di Benedetto, 1999; Pickett et al., 1999). It may be that Italian children aged 3-5 years have not yet acquired adult-like geminate production – in so far as this lack of shortening before geminates may affect the magnitude of contrastivity in trisyllabic words beginning with a WS pattern more so than trisyllabic words beginning with a SW pattern. That is, having to further shorten an already brief initial syllable may be particularly difficult for children of this age. We acknowledge that our interpretation is speculative given it is based on data from a single word (*tacchino)*. It would be helpful to conduct additional research with a greater number of words containing geminates. However, the constraints on stimuli selection for picture naming with 3-5 year olds (as outlined in our Method section) may make this difficult. Thus, it may be necessary to use other methods.

In summary, a key finding from the current study is that Italian children's familiarity with the dominant pattern of penultimate syllable stress for trisyllabic words may allow them to overcome the physiological speech-motor constraints discussed previously including production of rising contour and/or production of initial brief vowels associated with words beginning with a weak syllable (e.g., Allen & Hawkins, 1980; Ballard et al., 2012; Sundberg, 1979; DePaolis et al., 2008). In spite of this, production of stress contrastivity for trisyllabic

words beginning with a WS pattern that contain a medial geminate may pose challenges for young Italian children.

As an aside, we note that Ballard et al. (2012) reported much larger normalised PVIs for vowel duration for trisyllabic English words beginning with a WS pattern (grand PVIs averaged across all these word types ranged from -107.3 for 3 year olds to -121.7 for adults) than the trisyllabic Italian words beginning with a WS pattern reported in the current study (grand normalised PVIs averaged across all of these word types ranged from -43.22 for 3 year olds to -56.33 for adults). For trisyllabic words beginning with a SW pattern grand normalised PVIs were more comparable in the English and Italian data. It is possible that the greater stress contrastivity for the trisyllabic English words beginning with a WS pattern might be due to the presence of long vowels in the strong syllable in the items used in the Ballard et al. study. This kind of length distinction is not found in Italian. Due to these kinds of differences between the phonemic inventories of English and Italian we maintain that the primary focus of cross-linguistic discussion should be on comparing differences between child versus adult productions in English with differences between child versus adult productions in Italian.

In terms of our secondary aim we found that in standard Italian the grand normalised PVIs for vowel duration were consistently positive for trisyllabic words beginning with a SW pattern, and consistently negative for trisyllabic words beginning with a WS pattern, across all age groups. The direction of normalised PVIs for intensity and fundamental frequency was more variable. This finding regarding vowel duration is in line with previous research noting the importance of vowel duration in marking lexical stress in Italian (Bertinetto, 1980; Braun & Geiselmann, 2011; D'Imperio & Rosenthall, 1999). However, the current study does not allow us to conclude that intensity and fundamental frequency play no role in marking lexical stress in Italian.

Limitations and Future Directions

Ballard et al.'s (2012) study of the developmental trajectory of lexical stress production in English included a larger sample size (n = 40 children) than the study we report here (n = 27 children). However, in the current study we had 2.5 times the number of target words. In addition, we incorporated item analyses in the current study, unlike the Ballard et al study. Our sample size compares favourably with recent studies of Italian children's speech production. For example, Majorano and D'Odorico (2011) examined babbling and first words in 11 children aged 1-2 years (only 6 of whom produced polysyllabic words). Zanobini et al. (2012) assessed 30 children aged between 36 and 42 months.

As mentioned, the current study has revealed an interesting finding regarding how a word-medial geminate can affect the magnitude of stress contrastivity produced by children. We have speculated that children's lack of vowel shortening for vowels preceding word-medial geminates makes them *less* adult-like in terms of stress contrastivity for trisyllabic words beginning with a WS pattern. Conversely, for trisyllabic words beginning with a SW pattern, this same lack of vowel shortening for vowels preceding word-medial geminates may actually *facilitate* adult-like contrastivity. Unfortunately, our study was not designed to allow comprehensive examination of gemination. Additional research is needed in order to explore the developmental trajectory of Italian children's production of geminate consonants and how this affects stress contrastivity across words with different patterns of lexical stress.

Current cognitive and computational models of speech production are grossly under-specified with regard to lexical stress, particularly in relation to developmental influences on stress contrastivity. Levelt's (1992) psycholinguistic model made great gains in detailing the multiple stages of word production. Roelofs' (1997) computational model, WEAVER, drew on the notion of spreading activation to simulate key chronometric aspects of word production (see also Levelt, 2001; Schiller, Fikkert, & Levelt, 2004). The DIVA model provides more precise detail regarding motor planning, successfully modeling effects such as coarticulation (Bohland & Guenther, 2006). Unfortunately, none of these models is adequate in terms of

accommodating developmental influences on the magnitude of stress contrastivity during speech production. Perhaps the data we report here can inform future modelling efforts.

An applied field that will benefit from this project is speech pathology. Diagnosis and treatment of impaired stress contrastivity in apraxia of speech, autism spectrum disorders, hearing loss, and aphasia is currently undertaken in the absence of a solid evidence base (Peppé, 2009). What we do know about impaired lexical stress is primarily based on studies of English. For the first time we provide an acoustic analysis of the developmental trajectory of stress contrastivity in standard Italian. The data reported in our study may assist clinicians in diagnosing Italian children who have difficulties with stress contrastivity.

Table 1. Mean normalised PVIs (standard deviations in parentheses) for trisyllabic words beginning with a WS pattern and trisyllabic words beginning with a SW pattern. Data for children (averaged across ages) and adults are reported separately.

	PVI_duration	PVI_intensity	PVI_f_0
Children			
WS	-44.49 (12.95)	.71 (4.05)	3.51 (3.46)
SW	52.51 (17.76)	5.39 (3.54)	.11 (6.21)
Adults			
WS	-56.33 (11.50)	3.61 (3.55)	4.92 (4.24)
SW	56.99 (12.98)	7.36 (3.91)	-.71 (8.05)

Note that trisyllabic Italian words beginning with a WS pattern across the initial 2 syllables can be described as having stress on the penultimate syllable. Trisyllabic Italian words beginning with a SW pattern across the initial 2 syllables can be described as having stress on the antepenultimate syllable.

Table 2. Mean normalised PVIs (standard deviations in parentheses) for children at 3, 4, 5 years and adults (A) for trisyllabic words beginning with a WS pattern and trisyllabic words beginning with a SW pattern.

Age		WS			SW	
	PVI_duration	PVI_intensity	PVI_f_0	PVI_duration	PVI_intensity	PVI_f_0
3	-43.23 (14.59)	0.23 (6.25)	3.70 (4.43)	59.12 (20.75)	7.35 (5.49)	-0.41 (3.81)
4	-44.41 (12.73)	0.50 (2.00)	4.28 (2.22)	51.93 (18.62)	5.17 (1.48)	-0.55 (6.51)
5	-45.03 (13.28)	.99 (3.87)	3.12 (3.61)	50.09 (16.83)	4.69 (3.09)	0.59 (7.12)
A	-56.33 (11.50)	3.61 (3.55)	4.92 (4.24)	56.99 (12.98)	7.36 (3.91)	-.71 (8.05)

Note that trisyllabic Italian words beginning with a WS pattern across the initial 2 syllables can be described as having stress on the penultimate syllable. Trisyllabic Italian words beginning with a SW pattern across the initial 2 syllables can be described as having stress on the antepenultimate syllable.

Table 3. Mean PVI_duration (standard deviations in parentheses) for the item containing a word-medial geminate – ‘tacchino’ – for children at 3, 4, 5 and adults (A).

Age	PVI_duration
3	-39.97 (18.07)
4	-44.79 (34.47)
5	-54.81 (32.12)
A	-70.66 (15.14)

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