Infant-directed speech reduces English-learning infants' preference for trochaic words

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Over the past couple of decades, research has established that (1) infant-directed speech (IDS) facilitates speech, language, and cognitive development; and (2) infants are sensitive to the rhythmic structures in the ambient language. However, little is known about the role of IDS in infants' processing of rhythmic structures. Building on these two lines of research, whether IDS enhances infants' sensitivity to the predominant stress pattern (trochaic) in English was asked. To address this question, 9-month-old American infants were familiarized and tested with both trochaic (e.g., *lazy*) and iambic (e.g., *cartoon*) words presented in either IDS or adult-directed speech (ADS). Infants showed listening preference for the trochaic over iambic words when the speech was presented in ADS, but not in IDS. These results suggest that IDS attenuates infants' preference for trochaic stress pattern. Further acoustical analyses demonstrated that IDS provided less salient spectral cues for the contrasts between stressed and unstressed syllables in trochaic words. These findings encourage further efforts to explore the effects of IDS on language acquisition from a broader perspective. © 2016 Acoustical Society of America. [http://dx.doi.org/10.1121/1.4968793]

I. INTRODUCTION

When interacting with infants, caregivers typically adopt a unique speech register, referred to as infant-directed speech (IDS; Ferguson, 1964; Fernald, 1993; Snow, 1977), which is very different from the register used in adult-to-adult exchanges, namely, adult-directed speech (ADS). IDS is found to facilitate speech perception along several dimensions; however, the degree to which IDS may shape infants' rhythmic processing has yet to be determined. In this study, we took a first step and asked whether IDS enhances infants' sensitivity to the predominant stress pattern, namely, trochaic pattern, in English.

A. Infant-directed speech and infant speech processing

IDS is characterized by slower speaking rate, higher pitch, wider pitch range, shorter utterances, and longer pauses (e.g., Albin and Echols, 1996; Bergeson *et al.*, 2006; Bernstein Ratner and Pye, 1984; Burnham *et al.*, 2002; Fernald and Simon, 1984; Fernald *et al.*, 1989; Grieser and Kuhl, 1988; Papousek *et al.*, 1991; Stern *et al.*, 1983; Werker *et al.*, 1994). Decades of research has demonstrated that IDS plays an important role in regulating caregiver-infant interaction as well as in assisting speech, language, and cognitive development (Benders, 2013; Burnham *et al.*, 2002; Cutler and Norris, 1988; Fernald and Simon, 1984; Greenwood *et al.*, 2010; Hart and Risley, 1995; Kaplan *et al.*, 2002; Kitamura and Notley, 2009; Kuhl, 1997;

Papousek *et al.*, 1991; Thiessen and Saffran, 2004; Uther *et al.*, 2007; Werker and McLeod, 1989).

The melodic contours and exaggerated prosodic features of IDS are known to present language-independent sources of information that reflect universal parental behavior, namely, to express caregivers' positive affect and to maintain infants' attention (Fernald *et al.*, 1989; Grieser and Kuhl, 1988; Kitamura and Burnham, 2003; Trainor *et al.*, 2000). Indeed, typically-developing infants are sensitive to the prosodic properties in the speech and prefer IDS over ADS (Cooper and Aslin, 1990; Fernald, 1985, 1989; Fernald and Simon, 1984; Kitamura *et al.*, 2001; Kuhl, 1997; Werker and McLeod, 1989). With regard to the didactic function, infants who experience more IDS become more efficient in word recognition and have a larger expressive vocabulary by 24 months of age (Shneidman and Goldin-Meadow, 2012; Weisleder and Fernald, 2013). Although there has been substantial discussion about possible properties of IDS that might facilitate language acquisition (Fernald and Mazzie, 1991; Fernald and Simon, 1984; Kuhl, 1997; Peters, 1983), very few empirical studies have provided *direct* evidence of such facilitation. For example, Karzon (1985) showed that American English infants between 1 and 4 months discriminated the polysyllabic sequence [malana] from [marana] when the syllables were produced in IDS, but not when they were produced in ADS. Thiessen *et al.* (2005), using an artificial language task, found that American English 7.5-month-olds were better able to utilize statistical cues to word boundaries in IDS compared to ADS. In addition, Singh *et al.* (2009) assessed American English 7- and 8-month-olds' memory for words under IDS and ADS conditions, and found that they successfully recognized the words 24 h later

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when the words were presented in IDS, but not in ADS. Along similar lines, Ma *et al.* (2011) also reported a facilitatory role of IDS in word learning. They showed that 21-month-old American English children learned novel words from IDS, but not from ADS, although 27-month-olds could learn novel words from both registers. Finally, Song *et al.* (2010) investigated which acoustic properties of IDS facilitated infant speech processing in a word recognition experiment. Specifically, they tested American English 19-month-olds with natural and manipulated versions of IDS, and found that the slow speech rate and vowel hyperarticulation, but not the expanded pitch range, contributed to children's better performance.

Although a few prior studies provide some evidence of facilitatory effects of IDS on some aspects of infant speech processing, at least in the case of younger infants [although see Schreiner *et al.* (2016), for a study which found no effect of register on word segmentation in German 7.5- to 9-month-olds], the role of IDS on many other aspects of speech processing is still unknown. Crucially, no previous work has specifically investigated whether IDS promotes infants' processing of rhythmic structure, in particular, whether it facilitates their processing of lexical stress.

B. Infant processing of rhythmic structure

Infants are highly sensitive to the prosodic information in the speech input, such as syllable duration, pitch changes, and pauses (Cutler *et al.*, 1997; Jusczyk *et al.*, 1999; Nazzi *et al.*, 1998; Nazzi *et al.*, 2003; Nazzi *et al.*, 2000; Seidl, 2007). This sensitivity appears quite early and continues to develop through a complex interplay of linguistic and cognitive development (DeCasper and Spence, 1986; Jusczyk *et al.*, 1992; Mehler and Dupoux, 1994; Nazzi *et al.*, 1998; for a recent review, see Werker and Gervain, 2013). One of the prosodic properties that infants attend to during the first year of life is the lexical stress pattern. Indeed, by 2 months of age, English-learning infants detected changes in patterns of alternating strong-weak (trochaic) syllables (Jusczyk *et al.*, 1978). There were also indications that from the second half of the first year, infants began to attune to the prosodic properties in their native language. By 9 months of age, infants preferred words with the more frequent trochaic pattern over words with the less frequent iambic one in English (Jusczyk *et al.*, 1993). Similarly, Höhle *et al.* (2009) demonstrated the same bias in German (but not French) 6-month-olds. However, note that both studies used only ADS speech; therefore, these findings do not inform us whether/to what extent IDS may impact infants' sensitivity to native stress patterns.

Sensitivity to native stress patterns is crucial because stress is fundamentally important in the earliest stages of language acquisition, especially in the domain of sound discrimination, word segmentation, and word learning. For instance, 9-month-olds detected minimally distinct sounds in stressed syllables, but not in unstressed ones (Mattys *et al.*, 1999). Furthermore, stress has been implicated in possibly facilitating word segmentation in infants learning a stress-timed language. For example, Jusczyk *et al.* (1999) showed

that infants began to segment trochaic words (e.g., *kingdom*) from fluent speech by 7.5 months of age; however, the ability to segment iambic words (e.g., *guitar*) emerged later at 10.5 months. Similar strategies are also found in infants who are learning German (Höhle *et al.*, 2009) and Dutch (Houston *et al.*, 2000; Kuijpers *et al.*, 1998), languages that are rhythmically similar to English. On the other hand, French 7.5-month-old infants, who had been exposed to a language with a predominant iambic (WS) stress pattern, only segmented iambic words from the speech stream (Polka *et al.*, 2002). Equally important, stress is also encoded in the mental representation of word forms. Specifically, infants adopted a stress-initial strategy and encoded stress information as part of their proto-lexical representation (Archer *et al.*, 2014; Curtin *et al.*, 2012; Curtin *et al.*, 2005); moreover, it was the salient acoustic properties of lexical stress that facilitated word-object mapping in infants (Curtin, 2009).

C. The current study

In light of findings of the role of IDS in infant speech processing and infant's sensitivity to native stress, it is therefore critical to compare the effects of IDS and ADS on the perception of lexical stress by infant learners of languages like English. Although previous research has demonstrated a facilitatory role of IDS in several aspects of language acquisition, as opposed to ADS, there are independent grounds for questioning the assumption that IDS facilitates infants' perception of lexical stress contrasts. This is because analyses of English IDS acoustic cues to stress contrasts showed no cue enhancements. For instance, Albin and Echols (1996) analyzed speech samples of American English mothers speaking to their 6- and 9-month-old infants and to another adult (the experimenter). They found a reduction in the durational contrast between non-final stressed and final unstressed syllables in IDS, due to the greater degree of lengthening of all word/utterance-final syllables, thereby potentially reducing the perceptual distinctiveness of trochaic stress patterns in this register. Lee *et al.* (2014), in an analysis of speech samples of Australian English mothers talking to their infants and to other adults, found that prominence contrasts (as measured by various auditory-model derived metrics) between the vowels of stressed and unstressed syllables were reduced in IDS compared to ADS. In addition, Wang *et al.* (2015) analyzed trochaic words in the conversational speech of American English mothers of 4- and 11-month-old infants; they found no evidence of register differences in the use of durational, F0, or vowel quality cues to lexical stress.

Thus, in the present study, we explored the role of IDS in infant's processing of native lexical stress. Specifically, using the modified Headturn Preference procedure (Jusczyk and Aslin, 1995), we tested forty-eight 9-month-old English-learning infants' preference for trochaic and iambic word lists presented by either IDS or ADS. We predict that if IDS increases infants' sensitivity to lexical stress, 9-month-old English-learning infants would show a stronger preference for trochees over iambs in IDS condition. On the contrary, if

IDS hinders perception of lexical stress, then they would show a lesser degree of trochaic preference in the IDS condition, relative to the ADS condition.

II. EXPERIMENT

A. Methods

1. Participants

Forty-eight monolingual English-learning 9-month-old infants (24 females, 24 males) with no known history of developmental delay or hearing loss participated in the study. These infants were recruited from a Midwestern town through social media. They were between the ages of 8.26 and 10.03 months [mean (M) = 9.29, standard deviation (SD) = 0.47]. Informed consent was given to the caregivers prior to testing.

2. Stimuli

The stimuli consisted of 20 lists of English words. Each list consisted of ten bisyllabic words. In half of the lists, the words were all trochees; whereas in the other half, the words were all iambs. We matched as much as possible the vowels in the stressed syllables as well as the syllable structures across the two types of word lists. A young adult female native speaker of American English recorded the speech stimuli, in both IDS and ADS, in a sound attenuated booth. She was instructed to produce the stimuli as if to an infant (IDS) or to an adult (ADS).

3. Experimental design

Participants were randomly assigned to either the IDS or ADS condition. Each infant participated in both a familiarization phase and a test phase. Infants in the IDS condition listened to the stimuli produced in IDS register in both familiarization and test phases, while infants in the ADS condition listened to the stimuli produced in ADS register in both phases. Infants in both conditions were familiarized with 4 lists of words, two lists of trochees and two lists of iambs, and tested with the remaining 16 lists of words, 8 lists of trochees, and 8 lists of iambs. Each word list consisted of ten words and lasted approximately 15 s.

4. Apparatus and procedure

A modified version of the Headturn Preference procedure (Jusczyk et al., 1995) was used. Each infant was seated on a caregiver's lap in the middle of a double-walled IAC sound booth. The caregiver wore headphones, which played continuous music and speech babble to mask the stimuli. The booth was quiet and comfortable. There were three panels: a center panel and two side panels. On each of the three panels hung a monitor at eye level, which would play videos of a light blinking when triggered. Infants and caregivers sat in front of the center monitor. A camera was located behind the central panel to record the infant's behavior. The experimenter observed the infant in the control room and coded the infant's orientation regarding the direction and duration of head turns for each trial using a keyboard. All orientation data were stored in a computer data file. Each trial began with the video of a green light blinking on the center monitor. When the infant looked at the green light, the monitor was darkened and one of the two side monitors would begin to display the video with a red light blinking. When the infant oriented at least 30° in the direction of the red light on the monitor, the stimuli for that trial began to play. The audio output was fed to the loudspeakers beneath the two side monitors. The stimuli played until either the infant looked away for two consecutive seconds or the stimuli file was complete. At this point, the side monitor became dark and the sound stopped. Then the center monitor began to play the video with green light blinking in preparation for the next trial. The computer recorded the amount of time the infant oriented to the side monitors while the stimuli played. Orientation time was defined as the amount of time the infant spent looking at the side monitors. If the infant turned away from the monitor by 30° for less than 2 s, that time was not included in the orientation time, although the monitor continued to display the video and the loudspeaker to play sounds.

Each experimental session began with a familiarization phase and was followed by a test phase. During the familiarization phase, half of the infants received the trochaic list first and the other half the iambic list first, thereby eliminating the possibility of a bias resulting from a preference for the first pattern heard. Following Jusczyk et al. (1993), the familiarization phase was intended to acquaint the infants with the assigned position of each type of word list. Therefore, the trochaic word lists were consistently played through the loudspeaker on one side and the iambic word lists through the loudspeaker on the other side, with side counterbalanced across participants. Immediately after the familiarization phase, infants received 16 test trials presented in a pseudorandom order (i.e., no similar type was presented more than three times in a row). The order of the trials was randomized across participants. The dependent measures were the average orientation times across trials to trochaic and iambic word lists, respectively.

B. Results and discussion

The average orientation times to the trochaic and iambic trials in the test phase were 6.46 s (SD = 2.70) and 6.39 s (SD = 2.97) in the IDS condition, and 6.97 s (SD = 2.72) and 5.56 s (SD = 1.97) in the ADS condition. We submitted the data to a 2×2 repeated measures analysis of variance with Stress Pattern (trochee, iamb) as a within-subjects factor, and with Register (IDS, ADS) as a between-subjects factor. The results revealed a marginally significant interaction of Stress Pattern and Register, $F(1, 46) = 3.59$, $p = 0.064$, $\eta^2_p = 0.072$, and a significant main effect of Stress Pattern, $F(1, 46) = 4.42$, $p = 0.041$, $\eta^2_p = 0.088$; however, the main effect of Register was not significant, $F(1, 46) = 0.06$, $p = 0.803$, suggesting that infants looked equally long to the word lists presented in IDS and ADS. To understand the source of the interaction, we conducted planned comparisons for each condition to compare infants' orientation times to trochaic vs iambic trials. Results indicated that infants in the ADS condition looked significantly

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longer to the trochaic than to the iambic trials, $t(23) = 3.24$, $p = 0.004$ (all the reported t-tests were two-tailed); however, their orientation times to the trochaic and iambic trials in the IDS condition were not significantly different, $t(23) = 0.132$, $p = 0.896$, see Fig. 1.

These findings demonstrated that English-learning 9-month-olds preferred listening to trochaic over iambic words in the ADS condition, but not in the IDS condition. These results suggest that IDS attenuates rather than enhances infants' preference for the predominant stress pattern in English, as compared to ADS. In what follows, we conducted acoustical analyses on our speech stimuli in order to explore the possible acoustic cues that may have led to this outcome.

III. ACOUSTICAL ANALYSES

Following Lee *et al*. (2014) and Wang *et al*. (2015), we measured the duration, intensity, F0, vowel peripherality, spectral tilt, and L_{max} of the vocalic nuclei of all the stressed and unstressed syllables from our stimuli. All coding and analyses were done using Praat software (Boersma and Weenink, 2013). Stressed and unstressed nuclei for each word were annotated. For example, for the word *lazy*, [eɪ] was tagged as stressed, and [i] was tagged as unstressed. The annotation in this tier followed standard segmentation methods. The onset of the nucleus interval was defined as the first upward crossing after the onset of the periodicity. The offset was determined as an abrupt attenuation of energy, evident in both the waveform and the spectrogram.

A. Measurements

1. Duration, intensity, and F0

Acoustic measurements were extracted using Praat scripts. We extracted (1) mean duration in second (s); (2) mean intensity in dB; and (3) mean F0 in ERB. Formants
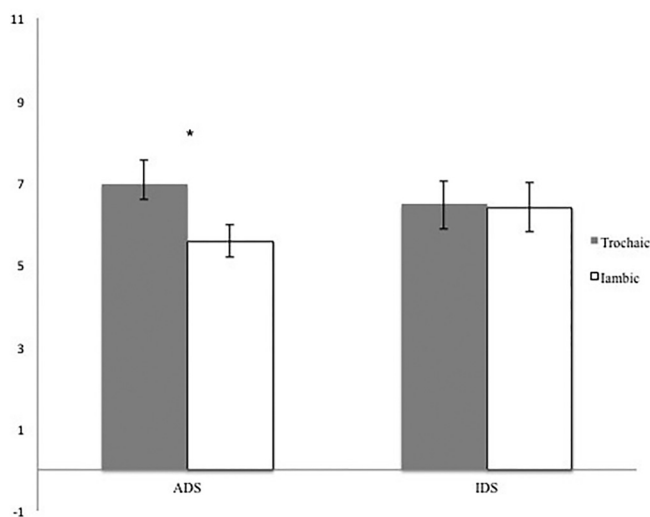

FIG. 1. 9-month-olds' orientation times to trochaic and iambic test lists, separated by register (IDS, ADS).

were identified from the peaks drawn from a linear prediction analysis of the acoustic signal.

2. Peripherality

To calculate vowel peripherality, we first retrieved F1 and F2 values of the corner vowels /a, i, u/ as instantiated in the *stressed* syllables containing these vowels in both trochaic and iambic words, separated by speech register (IDS, ADS). There were 43 tokens of corner vowels within each of IDS and ADS: 20 tokens (11 from trochaic words and 9 from iambic words) of /a/, 9 tokens (3 from trochaic words and 6 from iambic words) of /i/, and 14 tokens (7 from trochaic words and 7 from iambic words) of /u/. The examination of the distribution of F1 and F2 for each corner vowel within each register revealed that they were all within 2.5 SD from the mean; thus, all the data points were included to calculate the center of vowel space by averaging F1 and F2 of the three corner vowels within each register.

a. Full vowels. The first set of analyses excluded all the words containing syllabic consonants (e.g., *condone*, *contrive*) or schwas (e.g., *acquire*, *refer*). The reason to exclude schwas was because they are prototypically non-peripheral. We calculated vowel peripherality as the Euclidean distances from that center, $d = \sqrt{(\mu F1 - F1i)^2 + (\mu F2 - F2i)^2}$, where "$\mu$" indicates the center of vowel space and "i" the token under examination. The larger the d value, the more distant a given token is from that vowel's center of mass for that speaker (e.g., Bradlow *et al*., 1996). Vowel center and peripherality were calculated within each register because it was expected that IDS and ADS would have inherently different center and peripherality.

b. Schwas. The second set of analyses examined syllables with schwas. The motivation to examine schwas was because there is evidence that German infants only segmented trochaic words when the second syllable contained a schwa; however, they were not able to do so when the second syllable contained a full vowel (Bartels *et al*., 2009). This evidence opens up the possibility that in addition to prosodic information, segmental information, the distribution of schwas in particular, may also play an important role in infant processing of lexical stress. Specifically, given the non-peripheral nature of schwa, if ADS provides better exemplars of prototypical schwa, such that they are more closely distributed in ADS than in IDS, then this may provide an additional explanation to our findings that infants only showed a trochaic bias in ADS, but not in IDS.

To calculate the distribution of schwas, we first calculated the center of the schwas from unstressed syllables separated by stress pattern and register. We then calculated the peripherality (d) of each schwa from the center.

3. Spectral tilt

Spectral tilt refers to the decrease in energy across the spectrum, such that the energy is more concentrated at lower frequencies than at higher frequencies, with an average

decrease of 12 dB per octave (Klatt and Klatt, 1990). However, this attenuation is modulated by stress, such that in stressed syllables, the energy is more equally distributed across the frequency spectrum, with a resultant increase in perceived prominence (Sluijter et al., 1997). There is also evidence that spectral tilt is affected by register, with steeper spectral tilt in IDS than in ADS, due to its higher overall F0 and "softer" voice quality (Shinya et al., 2009). We therefore examined how spectral tilt changes as a function of stress in the two registers. Following Lee et al. (2014), we derived a measure of spectral tilt as follows: We used Praat to calculate the Band Energy Difference (BED) of all tagged vocalic nuclei, defined by the difference in dB between the mean spectral intensity in the bands between 500 and 4000 Hz and 0 and 500 Hz, with smaller BED values reflecting steeper spectral tilt.

4. Loudness

In addition, given the likely complex interplay between the individual measures, as well as the fact that vowel quality differed in stressed and unstressed syllables, we performed auditory model-based loudness analyses, which focused on the prominence of vowels/sonorant segments. Loudness measurements were taken using the Praat loudness model developed by Fastl and Zwicker (Fastl and Zwicker, 2006). Following Lee et al. (2014), the maximum loudness level (L_{max}) in phons of all vocalic intervals was calculated for both stressed and unstressed syllables, taking loudness measurements at 5 ms intervals from the onset to the offset of each vocalic interval.

B. Results

There was a total of 160 trochaic (80 IDS and 80 ADS) and 160 iambic words (80 IDS and 80 ADS) across all the 32 test word lists (10 words per list). We removed the data points whose difference value between stressed and unstressed vowels were more than 2.5 SD (the number of tokens included in the final analyses is reflected in the df in Table I and Table II). The average values for each acoustic measurement of the vowels in the stressed and unstressed syllables separated by register (IDS, ADS) are also summarized in Table I (trochaic words) and Table II (iambic words).

In order to examine whether stressed syllables were more prominent than unstressed syllables, we conducted a series of within-token paired-samples t-tests within each register (IDS, ADS). Results from the statistical analyses are reported in Tables I and II. Stress in IDS, in general, was cued in a very similar way to stress in ADS for both trochaic and iambic words. Specifically, stressed syllables had higher values than unstressed syllables on the measures of duration, intensity, and L_{max}, in both trochaic and iambic words across

TABLE I. Mean (SD) for each of the acoustic measurements: duration, amplitude, F0, Peripherality (full vowels and schwas), and L_{max} for **trochaic** words, separated by stress type (stressed, unstressed) and register (IDS, ADS). Also shown are the mean differences (SD) between stressed and unstressed syllables, as well as t and p values from statistical analyses.

	Stressed	Unstressed	Difference	t, p
Duration				
IDS	0.19 (0.06)	0.11 (0.05)	0.08 (0.08)	$t(78) = 8.65, p < 0.001$
ADS	0.15 (0.05)	0.09 (0.03)	0.06 (0.05)	$t(79) = 10.61, p < 0.001$
Intensity				
IDS	82.88 (1.21)	77.86 (3.02)	5.02 (3.39)	$t(70) = 12.47, p < 0.001$
ADS	82.24 (0.71)	76.44 (2.72)	5.80 (2.65)	$t(76) = 19.20, p < 0.001$
F0				
IDS	8.05 (0.59)	5.09 (0.84)	2.96 (0.82)	$t(77) = 31.75, p < 0.001$
ADS	5.23 (0.49)	4.07 (0.42)	1.16 (0.59)	$t(78) = 17.40, p < 0.001$
Peripherality				
Full vowel				
IDS	2.59 (1.08)	2.66 (1.11)	−0.07 (1.29)	$t(22) = −0.24, p = 0.809$
ADS	2.59 (0.82)	2.66 (1.13)	−0.07 (1.40)	$t(23) = −0.24, p = 0.815$
Schwa				
IDS	—	0.79 (0.50)	—	—
ADS	—	0.72 (0.49)	—	—
Difference	—	0.070 (0.70)	—	—
t, p	—	$t(81) = 0.64$ $p = 0.525$	—	—
BED				
IDS	−5.87 (6.28)	−6.64 (4.84)	0.78 (6.95)	$t(73) = 0.96, p = 0.340$
ADS	−3.90 (6.25)	−5.92 (4.51)	2.03 (7.19)	$t(77) = 2.49, p = 0.015$
L_{max}				
IDS	100.99 (1.86)	94.83 (3.35)	6.16 (4.31)	$t(75) = 12.45, p < 0.001$
ADS	101.11 (1.79)	93.52 (3.77)	7.59 (4.65)	$t(74) = 14.13, p < 0.001$

TABLE II. Mean (SD) for each of the acoustic measurements: duration, amplitude, F0, Peripherality (full vowels and schwas), and L$_{max}$ for **iambic** words, separated by stress type (stressed, unstressed) and register (IDS, ADS). Also shown are the mean differences (SD) between stressed and unstressed syllables, as well as t and p values from statistical analyses.

	Unstressed	Stressed	Difference	t, p
Duration				
IDS	0.06 (0.03)	0.24 (0.08)	−0.18 (0.011)	$t(64) = -20.03, p < 0.001$
ADS	0.05 (0.02)	0.20 (0.07)	−1.14 (0.08)	$t(76) = -16.42, p < 0.001$
Intensity				
IDS	78.00 (2.62)	81.80 (1.54)	−3.80 (3.07)	$t(75) = -10.80, p < 0.001$
ADS	79.45 (2.62)	81.03 (1.34)	−1.58 (3.17)	$t(74) = -4.31, p < 0.001$
F0				
IDS	5.37 (0.42)	7.52 (0.83)	−2.15 (0.82)	$t(76) = -22.92, p < 0.001$
ADS	4.68 (0.38)	4.70 (0.31)	−0.03 (0.42)	$t(78) = -0.55, p = 0.582$
Peripherality				
Full vowel				
IDS	2.76 (0.97)	2.73 (1.12)	0.03 (1.40)	$t(40) = 0.12, p = 0.902$
ADS	2.72 (1.06)	2.52 (1.06)	0.20 (1.62)	$t(40) = 0.79, p = 0.437$
Schwa				
IDS	1.29 (0.59)	—	—	—
ADS	1.15 (0.57)	—	—	—
Difference	0.14 (0.82)	—	—	—
t, p	$t(64) = 1.01$ $p = 0.318$	—	—	—
BED				
IDS	−14.31 (7.61)	−4.24 (6.55)	−10.08 (9.09)	$t(78) = -9.85, p < 0.001$
ADS	−10.81 (6.74)	−3.33 (6.25)	−7.48 (9.45)	$t(79) = -7.08, p < 0.001$
L$_{max}$				
IDS	87.22 (4.93)	101.64 (2.14)	−14.42 (5.74)	$t(79) = -22.45, p < 0.001$
ADS	88.19 (5.42)	100.78 (2.44)	−12.59 (6.41)	$t(75) = -17.13, p < 0.001$

registers. In addition, no significant differences were found between stressed and unstressed syllables for the peripherality measures across stress types and registers. However, there were some differences between IDS and ADS: (1) In trochaic words, stressed syllables had significantly less negative BED than unstressed syllables in ADS, but there was no difference in IDS; and (2) In iambic words, F0 was significantly higher in stressed syllables than unstressed syllables in IDS, but there was no significant difference in ADS.

IV. DISCUSSION

Although IDS is often assumed to facilitate infant language acquisition, empirical studies testing this claim are scarce. Moreover, the effects of IDS on infants' processing of prosodic structure have received even less attention. In this study, we took a first step to explore the role of IDS in infants' processing of lexical stress. We found that whereas 9-month-olds preferred trochaic to iambic stress patterns in ADS, they showed no such preference when the speech stimuli were presented in IDS. In order to explore possible explanations for this difference, we conducted acoustical analyses of the speech stimuli using a variety of acoustic measurements, duration, intensity, F0, vowel peripherality, BED, and L$_{max}$. The results indicated that although stress was cued quite similarly in IDS as in ADS, there were some differences. First, in trochaic words, stressed syllables had

significantly less negative BED than unstressed syllables in ADS, but there was no difference in IDS. Second, in iambic words, stressed syllables had a significantly higher F0 than unstressed syllables in IDS, but there was no difference in ADS.

A. Why IDS hinders infants' preference for trochees

The finding that IDS reduces infants' preference for trochaic patterns seems to be in contrast with the results of the empirical studies discussed above showing facilitatory effects of IDS in speech processing (Karzon, 1985; Liu et al., 2003; Ma et al., 2011; Song et al., 2009; Thiessen et al., 2005). One possible explanation of this processing advantage of ADS over IDS for lexical stress is that ADS may have provided more salient acoustical cues for infants to detect stress difference between trochaic and iambic words. It should be noted that infants' and adults' cue weighting strategy for stress is different. Previous work has shown that adults rely on a combination of cues, but not spectral tilt alone, for the perception of stress in most languages (e.g., Gordon, 2004; Gordon and Applebaum, 2010); however, 9-month-old infants can use spectral tilt alone or convergent cues to stress in boundary identification (Thiessen and Saffran, 2004). Thus, it is possible that the reason that infants in our study listened longer to trochaic than iambic words in ADS, but not in IDS, is because ADS

provides more salient age-appropriate acoustic cues, specifically spectral tilt, for trochaic stress detection.

B. Implications for the role of IDS on language acquisition

These findings provide additional information to the debate regarding the underlying mechanisms of IDS to enhance learning. On the one hand, some have argued that IDS promotes language acquisition because it provides enhanced perceptual cues and well-specified linguistic information that are beneficial to speech processing (e.g., Kuhl, 1997; Uther et al., 2007). However, much recent work has called this finding into question (Cristia and Seidl, 2014; Lee et al., 2014; Martin et al., 2015; McMurray et al., 2013; Wang et al., 2015). This emerging literature, on the contrary, suggests that IDS is not a specifically didactic signal (Cristia and Seidl, 2014; McMurray et al., 2013; Wang et al., 2015), and may even be a less clear signal than ADS (Lee et al., 2014; Martin et al., 2015). Thus, it could be that IDS enhances language acquisition because of its emotional and attentional content (Singh et al., 2004).

However, the answer to this debate is still inconclusive for the following reasons. First, it is possible that the mechanisms underlying the facilitatory role of IDS in language acquisition may change across infant development. For younger infants, who pay more attention to the exaggerated prosodic contours and positive affect in the speech (Kitamura and Burnham, 1998; Singh et al., 2002), the facilitatory role of IDS may be through engaging infant attention. In contrast, older infants, with more advanced speech perception abilities, may be more attracted to the structural aspects of speech (McRoberts et al., 2009), and thus actively seek salient linguistic information in speech (Newman et al., 2006). This also implies that infants would show increased attention to other speech registers over IDS if these registers provide clearer linguistic cues than IDS does. Indeed, although numerous studies have demonstrated that young infants in general prefer listening to IDS over ADS (Fernald and Simon, 1984; Fernald et al., 1989; Kitamura and Burnham, 2003; Kuhl, 1997), evidence has also shown developmental changes in their auditory preference for this speech register. For example, Hayashi et al. (2001) found Japanese young infants prefer IDS over ADS; however, 7- to 9-month-olds showed no preference. In a more recent study, Newman and Hussain (2006) found a similar lack of preference for IDS at 9 months in English-learning infants. The current results seem to be echoing these findings because infants in our study looked equally long to IDS and ADS stimuli, suggesting that they may be at the transition of a change in preferences.

Second, evaluating the role of IDS on language acquisition should also take into consideration the nature of the linguistic task, because it is possible that whereas IDS provides clearer linguistic cues than ADS in one domain, the reverse may be true in another domain. Thus, our findings that IDS provides less salient stress cues does not necessarily contrast with previous findings showing that IDS exhibits clearer cues than ADS, such as longer pauses (e.g., Fernald and Simon, 1984), slow speaking rate, and larger vowel spaces (e.g., Kuhl, 1997; Liu et al., 2003; although see Martin et al., 2015; McMurray et al., 2013). This is because the exaggerated phrasal-level prosodies in IDS may have disturbed the realization of lower-level prosodic constructs, lexical-level rhythmic structures in particular, leading to less salient contrasts between stressed and unstressed syllables in trochaic words in IDS (Cho, 2006; Gordon, 2003). However, the properties at the segmental level may be less affected. Therefore, the role of IDS in infant speech processing may be task-dependent such that while IDS facilitates infant speech processing in one linguistic task (e.g., vowel discrimination; word learning), it may hinder their speech processing in another task (e.g., stress detection).

Finally, note that the acoustic profile of stimulated IDS might differ from that of real-world IDS. However, to our best knowledge, there is only one study that has compared acoustical profiles of stress between IDS and ADS collected in a more natural setting (Wang et al., 2015). Specifically, they analyzed trochaic words in the speech of 20 mothers who were describing objects to their own infants (IDS) and an experimenter (ADS) in a laboratory. Results showed that while stressed and unstressed vowels differed between IDS and ADS with respect to F0, and trended in similar directions for vowel peripherality, neither set differed in duration. Most importantly, the register differences were equally marked in both stressed and unstressed syllables, suggesting that stress cues are not specifically enhanced in IDS as compared to ADS. However, they did not examine the spectral cues. Further studies are encouraged to examine the acoustical properties of stress in real-world IDS.

C. Implications for word segmentation

Finally, how do our findings bear on the long-standing puzzle of infant word segmentation in the language acquisition literature? Much of the linguistic input that infants receive consists of continuous speech with few easily discernible word units; therefore, a first step to learn words of a language is to extract words from the speech flow. Notwithstanding the challenges, infants succeed in this task from the latter half of their first year (Jusczyk et al., 1999). If IDS does not provide clear cues for stress, how would we reconcile our results with previous suggestions that infants adopt the Metrical Segmentation Strategy (MSS) and treat the stressed syllable as the beginning of a word (Cutler and Norris, 1988; Johnson and Jusczyk, 2001; Jusczyk et al., 1993; Jusczyk et al., 1999)?

First, MSS does not require infants to distinguish between trochaic and iambic stress patterns; it only requires them to identify stressed syllable from unstressed syllable, and then treat stressed syllable as word-initial. In addition, our results do not imply that infants are unable to distinguish between trochaic and iambic stress patterns from IDS at all; instead, our results only indicate that infants are better able to recognize that trochaic words in ADS fit their representations of prototypical phonological words in the native language. On this account, it is possible that with more exposure, infants would also show a preference for trochaic

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patterns in IDS. It is also important to note that although IDS does not provide as clear stress cues as ADS does, stress cues are nevertheless present in IDS. Therefore, infants may have identified the two stress patterns equally well in both IDS and ADS, but because their interest in the trochaic words was better sustained in ADS, either due to attentional and/or acoustic reasons, they showed a trochaic preference more reliably in the ADS condition.

Second, it is important to point out that although caregivers tend to use IDS when speaking to young infants, this speech style constitutes only a subset of linguistic input that infants receive. In addition to IDS, infants may also overhear a large amount of other speech, ADS in particular. Therefore, infants may develop their sensitivity to stress patterns from listening to ADS, and then apply this knowledge to all the other types of speech. However, this research does not allow us to directly test this hypothesis and we encourage future studies to systematically examine the relationship between the quantity of IDS and ADS that infants receive, infants' preference for predominant stress patterns, and their segmentation abilities.

V. CONCLUSIONS AND FUTURE DIRECTIONS

In summary, the current study took an important step toward understanding the role of IDS in infants' processing of rhythmic structure. We showed that IDS reduced 9-month-olds' preference for trochaic words as compared to ADS. The reduction in preference may be due to the fact that IDS provides less salient age-appropriate acoustic cues for the detection of trochaic stress pattern as compared to ADS. Future empirical studies are encouraged to manipulate the acoustic cues and test infants' sensitivity to trochaic and iambic stress patterns in order to identify their cue weighting strategy for stress detection. In addition, our findings provide a window to look beneath the surface prosodic characteristics of IDS and provide additional information relevant to the current debate on the mechanisms underlying the facilitatory role of IDS in promoting language acquisition. Given that infants' preference for IDS changes across development, so do the properties of IDS directed to infants of different ages, future longitudinal research on the transition of infants' attention from IDS to ADS, and on how this may go along with the development of speech perception and language development, may have significant theoretical and clinical implications.

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