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Is prosodic production driven by lexical development? Longitudinal evidence from babble and words.

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Is prosodic production driven by lexical development?

Longitudinal evidence from babble and words.

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Abstract

This study investigated the relation between lexical development and the production of prosodic prominence in disyllabic babble and words. Monthly recordings from nine typically developing Belgian-Dutch-speaking infants were analysed from the onset of babbling until a cumulative vocabulary of 200 words was reached. The differentiation between the two syllables of isolated disyllabic utterances was computed for f0, intensity and duration measurements. Results showed that the ambient trochaic pattern emerged in babble, but became enhanced in words. Words showed more prosodic differentiation in terms of f0 and intensity and a more even duration ratio. Age or vocabulary size did not predict the expansion of f0 or intensity in words, whereas vocabulary size was related to the production of more even-timed syllables. The findings are discussed in terms of lexicalist accounts of phonetic development and a potential phonetic highlighting function of first words.

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Introduction

Speech is not a uniform, constant signal. Instead, it evokes the impression of melodic and rhythmic fluctuations, with certain parts (i.e. words, syllables) standing out more than others. The patterning of alternations between stronger and weaker syllables belongs to the study of prosody. Prosody seems to be a universal feature of human languages, as it has also been described in sign languages, which do not use the acoustic modality (Brentari, 1998). This paper aims to study the development of prosodic prominence in early utterances, babble and words, of typically developing infants acquiring Belgian Dutch. Moreover, the impact of the emergence of vocabulary on prosodic abilities is of particular interest in this study?.

Prosodic phenomena have been described at several levels. At word level, the most prominent syllable is said to bear WORD STRESS, e.g. the syllable *straw* in *strawberry*. SENTENCE STRESS or SENTENCE ACCENT denotes the most prominent word at the sentence level (for in-depth discussions, see Nespor and Vogel, 1986 and Selkirk, 1984). Acoustically, prominence at different linguistic levels is usually the result of the single or combined use of an increase in fundamental frequency (f0), intensity and duration in syllables (Lieberman, 1960; Kochanski, Grabe, Coleman, & Rosner, 2005).

The acoustic properties of word stress seem to be highly salient to infants and they already play a role from birth onwards (Sansavini, Bertoncini, & Giovanelli, 1997). Studies focusing on the perception of word stress in the first year of life confirm this early sensitivity by showing a preference for the predominant stress pattern of the ambient language (Friederici, Friedrich, & Christophe, 2007; Jusczyk, Cutler, & Redanz, 1993). These results with very young infants suggest that it is possible to acquire the acoustic correlates of stress through a purely bottom-up, acoustic strategy. However, the acoustics of prosodic phenomena are not always transparent. Pierrehumbert (2003) offers a thorough discussion of the problem of phonetic

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variability in acquisition, pointing out that frequently a one-to-one relation between a prosodic phenomenon and an acoustic cue may not be evident: different acoustic correlates of stress are used across languages and talkers (Nespor, Shukla, van de Vijver, Avesani, Schraudolf, & Donati, 2008; Sluijter & van Heuven, 1995).

Experimental evidence further suggests that a bottom-up acquisition strategy cannot be the sole mechanism, since the manner in which word stress is encoded and processed also depends on its function within a language (Cutler, 2005; Dupoux, Sebastian-Galles, Navarrete, & Peperkamp, 2008). For instance, Skoruppa et al. (2009) found that the acoustic sensitivity of nine-month-old infants was determined by the lexical function of word stress in the ambient language. Infants were more sensitive to changes in stress patterns if they acquired a language which uses contrastive lexical stress to differentiate between homonyms, like Spanish, than when acquiring a language with fixed word stress, like French. Hence, the phonology of stress and its role in the vocabulary influences the ability of infants to abstract and store patterns of the acoustic input.

A similar situation has been described in the literature on early speech production, where a role for the infant's vocabulary in learning to produce word stress has been posited. This suggestion emerged because although some research found evidence that infants potentially had the necessary control of the acoustic cues for the production of prominences in speech, they did not always apply this consistently, or in accord with the stress pattern of their native language (Davis, MacNeilage, Matyear, & Powel, 2000). Indeed, findings of the early acquisition of word stress are not always conclusive, and there is conflicting evidence regarding the use of prosodic cues in babble and words. For example, whilst Hallé, De Boysson-Bardies, and Vihman (1991) reported language-appropriate control of f0 contours for eighteen-month-old French and Japanese infants, with French infants mainly producing rising and Japanese infants falling f0 contours,

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Vihman, DePaolis, and Davis (1998) found no language-specific strategies in the use of f0 and intensity on first disyllabic words of English and French infants. Hallé et al. (1991) found that vowel duration in the babble and words of their participants showed features of the ambient language: French infants displayed final syllable lengthening whereas Japanese infants did not, as this is also reduced in adult Japanese. In contrast, Vihman et al. (1998) and Davis et al. (2000) found little overall evidence for final syllable lengthening in disyllabic babble of seven- to fourteen-month-old English infants in comparison to adults.

Davis et al. (2000) approached these inconsistent findings by comparing disyllabic babbled utterances that were judged by adult raters to be clearly stressed with those that were not. Fewer than half of the babbled utterances were judged to contain a clearly prominent syllable, but in these clearly stressed utterances, f0, intensity and duration were produced in a similar manner to a control group of adult speakers. Furthermore, there was no obvious influence of the predominant strong-weak (trochaic) pattern of English word stress in the clearly stressed syllables. Instead, infants seemed to follow individual preferences for stress assignment, with some producing mainly trochaic forms whilst others favoured iambs (weak-strong). Davis et al. (2000) concluded that infants had the capacity to render the necessary cues for prominence, but did not do this consistently in babbled utterances. Moreover, even when they were producing adult-like cues, the preferred adult stress pattern was not yet evident.

These findings led DePaolis, Vihman and Kunnari (2008) to conjecture that prosodic control may emerge with the advent of first words. They therefore compared the disyllables at the four-word-point (i.e. the first recording in which the infant spontaneously produced four different identifiable words, with ages ranging from 10- to 18-months) in French, Welsh, English and Finnish. These languages were chosen because the first two have predominantly iambic word stress patterns and the latter have a majority of trochaic word forms. These stress patterns were

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however not clearly discernible in babble. They argue that language-specific differences in the use of acoustic cues might only emerge at around eighteen months, when relatively more words than babble are produced. All four groups realised durational differences in line with their target language. It was concluded that 'a more finely tuned use of prosody may require a level of attention to linguistic detail that begins to be possible only as word production becomes well established' (DePaolis et al., 2008: 417). It should however be noted that this hypothesis could not be verified with inferential statistics, as the study only included the very beginnings of vocabulary acquisition and therefore yielded an insufficient number of words for statistical comparison to babble.

The hypothesis of DePaolis et al. (2008) is especially relevant, as theories emphasising the role of vocabulary in phonetic and phonological development have gained increasing interest (see e.g. Edwards, Beckman, & Munson, 2004; Edwards, Munson, & Beckman, 2011; Stoel-Gammon, 2011; Vihman, 2009). Pierrehumbert (2003) conceptualised phonetic development as the process of abstracting phonetic detail over stored lexical items. Werker and Tees (2005) have argued for a cascading model of perceptual tuning for speech sounds, where complex and integrated tasks such as word learning rest on earlier, more basic sensory acquisition of phonetic categories. These levels are interdependent and linked by feed-forward as well as feed-backward mechanisms, so that lexical representations can in turn guide the uptake of new phonetic information to establish and solidify categories.

These theories were examined in children and adults in a number of studies. Munson (2001) used a nonsense word repetition task to investigate the influence of lexical factors on speech production in three-year-old children and adults. Children repeated less frequent phoneme sequences with reduced accuracy, longer durations and more phonetic variability. Adults' productions were also affected, with less fluent and more variable repetitions of infrequent

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sequences. This showed that phoneme-sequence frequency effects in the vocabulary had a direct impact on children's phonological abilities to repeat novel words, whilst for adults it had an effect on phonetic skill. The relationship between vocabulary and speech production in children was further explored by Edwards et al. (2004), who found that children with smaller vocabularies showed a larger influence of lexical frequency on the repetition accuracy of phoneme sequences in nonsense words. Again, low-frequency sequences had longer durations and more phonetic variability than sequences with high lexical frequency. It was argued that children with larger vocabularies had extracted more robust and flexible independent representations for each phoneme and were therefore able to extend them to new contexts more easily. Finally, Storkel (2001; 2003) showed that novel word learning was affected by the phonotactic probability contained within the words: words with sound sequences that were more common in children's lexicons were learned more easily. In summary, these studies suggest that different aspects of the lexicon influence phonological and phonetic abilities in children and adults. These factors are the vocabulary size and the frequency and phonotactic probabilities of phoneme sequences contained in the lexicon.

Given the link between lexical and phonetic/phonological abilities in later developmental stages and adulthood, the next question is how early the influence of higher-order language processing can be detected on lower-level phonetic acquisition. The studies reviewed in the previous paragraph showed lexical effects on segmental development, but the impact of vocabulary acquisition on prosodic development is an under-researched area. Moreover, recall that DePaolis et al (2008) were not able to confirm the link between the emergence of stable, language-specific stress patterns and the appearance of words through inferential statistics.

The present study therefore seeks to begin to address this gap in the literature by means of a longitudinal phonetic study of prominence patterns in spontaneous speech and by looking at

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disyllabic babble and first words. This study not only compares the prelexical and lexical stage, but also includes babble which is produced during the lexical stage. By comparing prelexical and lexical utterances which occur at the same time in development, it is possible to create a more complete picture of the acquisition of prominence than in previous studies. Fundamental frequency, intensity and duration were measured in the utterances of infants acquiring Belgian-Dutch, from the onset of babbling until a vocabulary of 200 words was reached. By including a longer developmental time span than DePaolis et al. (2008), we aim to assess the effect of vocabulary development through a direct comparison of disyllabic babble and words over time. Just like DePaolis et al. (2008), the present study does not make representational claims for the prosodic phenomena measured, instead the focus is on the infants' ability to render the acoustic surface form of prominence in Dutch, and whether the emergence of vocabulary affects this ability.

To summarise, two sets of research questions are the focus of the present study:

1. Is the acoustic realisation of prosodic differentiation more prominent in words than in babble? Is there a bias toward the trochaic stress pattern, and if so, is this more prominent in words than in babble?

2. Is the development of the acoustic correlates of stress predicted by infants' vocabulary size, or is stress mastered early in the production of words?

For the first research question, if DePaolis et al's (2008) prediction is correct, the ambient trochaic pattern will be clearly present in early words and individual acoustic cues should show greater differentiaton across stressed and unstressed syllables in words than in babble. It is also hypothesised that infants will be aiming at a strong-weak (trochaic) pattern in words, since in Dutch, the adult lexicon is predominantly trochaic (Cutler, 2005; Daelemans, Gillis, & Durieux,

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1994; Schiller, Meyer, Baayen, & Levelt, 1996)[1]. For babble, it is doubtful whether a clear effect of the strong-weak pattern will be evident, given the ambiguous results of the literature on babbling.

The hypothesis for the second research question is less clear-cut, as there are two equally likely outcomes. As some accounts suggest that phonetic development unfolds as an abstraction over an increasing mass of lexical items (Pierrehumbert, 2003; Vihman, 2009), it might be the case that an infant's vocabulary size determines how detailed phonetic representations are. Alternatively it can be hypothesised that the nature of lexical utterances themselves strengthens phonetics, i.e. the fact that they are spoken with communicative intent and have linguistic representations may already be enough to increase the infant's ability to produce more differentiated prominence patterns. Therefore, although the lexical status of disyllables should influence cues, an effect of vocabulary size per se will not be seen.

Materials and Method

Participants

The data for this study were taken from the CLiPS Child Language Corpus (CCLC), which is a collection of longitudinal audio-video data and transcriptions of 40 typically developing Belgian-Dutch acquiring infants.

For the purpose of this study, 9 children were randomly selected from the corpus. The infants were recruited from day-care centres, families known by the researchers and by announcements. The infants had been raised in monolingual homes acquiring the standard variety of Belgian Dutch (Verhoeven, 2005). All children were tested for congenital hearing loss in the first month of life by means of an otoacoustic emissions test. All the infants had normal hearing

[1] Although note that for duration, utterance-final lengthening may also influence the realisation of prominences in stand-alone utterances and obscure word stress effects (White & Turk, 2010; Sluijter & van Heuven, 1995).

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and no cases of otitis media were reported. The typical development of these children had been established on the basis of parent report and a checklist of the attainment of communicative and motor milestones, which is largely based on the checklist developed by KIND EN GEZIN, the Belgian infant welfare centre (Molemans, van den Berg, Van Severen, & Gillis, 2011). Normal language development was verified by means of the Dutch version of the CDI (N-CDI) administered at ages (years; months) 1;0, 1;6 and 2;0 (Zink & Lejaegere, 2001).

The mean age of these children at the beginning of the recordings was 0;06 (*SD* = 0;00.22). The mean age at the cut-off point of 200 words was 1;10 (*SD* = 0;03) (see *Data selection* for more information on the cut-off point). The ages of the individual children at the time of recording are specified in Table I.

INSERT TABLE I. ABOUT HERE

Corpus

The CCLC consisted of monthly recordings of spontaneous interactions between the children and their caretakers in their home environment. For more details on the corpus and transcription, see Van Severen, Gillis, van den Berg, De Maeyer, and Gillis (2013). A JVC digital video camera with built-in unidirectional microphone was used to record the data. Recordings lasted 60-90 minutes and the fragments during which the child was most vocally active and in uninterrupted interaction with a caretaker were selected. The final selection was approximately 20 minutes long.

The recordings were phonemically transcribed following the CHAT conventions (MacWhinney, 2000). The criteria for distinguishing words (lexical items) from babble were based on Vihman and McCune (1994). In order to qualify as a lexical item, utterances had to meet at least two out of three criteria: The first was based on the recurring interactional context in which the utterance occurred: i.e. a context where no other word could fit (e.g. the child utterance

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baba is interpreted as *bal* 'ball' as it was produced regularly whilst the child showed a ball), or the mother's identification clarified the meaning (e.g. the child utterance *baba* was interpreted as *bal* 'ball' by the mother). Secondly, the shape of the vocalisation was used as a criterion: it was either an exact phonological match or it matched two or more segments of the target (i.e. *pal* for *bal* 'ball'), or the utterance matched the target in its intonation contour or prosody. The third criterion took into account the relation to other vocalisations: the utterance was imitated or all occurrences of the utterance were identical (i.e. consistent use of *popo* for *opa* 'grandpa').

CHAT transcriptions were converted to a Praat (Boersma & Weenink, 2014) TextGrids using the CHAT2PRAAT function in the CLAN program (MacWhinney, 2013). The video files were converted to audio files using Free-Video-Converter ("Free-Video-Converter," 2012). The resulting TextGrids were time-aligned to the audio files at the utterance level, as illustrated in Figure 1.

INSERT FIGURE 1 ABOUT HERE

Data selection

For the present study, speech data were included from the ONSET OF BABBLING until children had reached a CUMULATIVE VOCABULARY of 200 words. This cut-off point was chosen because it provided enough relevant data to include all children in statistical analyses. Moreover, vocabulary level as a developmental point is used in other studies (Vihman et al., 1998). Cumulative vocabulary is used as a standard measure to track lexical development in psycholinguistic studies (Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Vanormelingen, De Maeyer, & Gillis, 2015), and it is based on a list of the word forms a child produces per individual recording session in a longitudinal study. The first cumulative number of vocabulary items comes from the number of words in the first recording session. For every recording that follows, the list of word types in the new session is compared to the previous one, and the

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number of new word forms produced are added to the cumulative vocabulary count. The period over which data were collected thus spans the onset of babbling, the emergence of first words and, as vocabulary sizes increased, the appearance of two and multiword utterances (Bates & Goodman, 1997).

Onset of canonical babbling was determined by a True Canonical Babbling Ratio (tCBR) of 0.15 or higher (Chapman, Hardin-Jones, Schulte, & Halter, 2001; Molemans et al., 2011). The tCBR is the proportion of syllables with true consonants (i.e. all consonants except glottals (/h/, glottal stop) and glides (/w/, /j/)) over all syllables produced. Since a longitudinal approach was taken in the current study, no artificial boundaries were placed between a babbling phase and a lexical phase as there was a transitional period where babble and words co-occured.

Inclusion criteria for disyllables. The waveforms and spectrograms associated with the speech files were examined in order to identify the disyllabic babble and words to be tagged in the PRAAT TextGrids (see Figure 1). Sound sequences were considered to be disyllables when they consisted of two vocalic phases minimally separated by a clear consonantal phase (see Segmentation criteria for consonants and vowels for specification). Additional consonants flanking the vocalic sections were allowed. The inclusion criteria for the disyllables were based on DePaolis et al. (2008). In order to be considered a single unit, the disyllables had to occur within the same intonation contour or adjacent to a prosodic break such as a pause or an in-breath at the beginning of a new breath group (Lieberman, 1984). Furthermore, disyllables had to be clearly separated from the surrounding speech by a silence of at least 400 ms with an intersyllabic pause of less than 400 ms. For a small number of items produced at a low speech rate, the pause criterion was relaxed up to 500 ms as long as the two syllables were part of a single intonation contour, indicating cohesion (Cruttenden, 1986). However, lexical items from a multiword context were not included in this study. Disyllables were excluded if there was concurrent speech

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or noise or if they were produced with a creaky, breathy, excessively loud or whispery voice. An example of a selected utterance is provided in Figure 1.

The recordings in the range studied contained a total of 40 928 child utterances, of which 27 807 were prelexical (i.e. babble and vocal play) and 13 121 lexical. The inclusion criteria significantly reduced the number of utterances analysed. The number of babbled and lexical disyllables per subject is summarised in Table II.

INSERT TABLE II. ABOUT HERE

Segmentation criteria for consonants and vowels. The disyllables identified by the procedure described above were further segmented into consonants and vowels, since the acoustic measurements in this study were conducted in the vocalic portion of each syllable. Figure 1 illustrates the annotation of an utterance. The waveform, spectrogram, f0 and intensity curve were used (a) to determine the word boundaries and (b) to segment the disyllables into consonants and vowels. The segment boundaries were identified on the basis of the consistent application of the segmentation criteria which are described in detail in DePaolis et al. (2008) and to which the interested reader is referred to for more information. Since DePaolis et al. (2008) did not specify any criteria for the segmentation of /l/, the onset and offset of the lateral approximant were determined on the basis of the discontinuity on the spectrogram in the intensity and/or frequency of the formants of /l/ and those associated with the preceding or following vowel.

Reliability of the annotations

The data were annotated by the author IDC. Approximately 20% of the data (n = 250) was re-annotated by the author MP. The reliability of the placement of the segment boundaries was analysed by means of the Pearson's product-moment correlation between the time points of both annotators. The correlation between both sets of annotations was 0.99 (p < .001), which indicates excellent inter-annotator agreement; annotators located the boundaries of segments at

virtually the same time points.

Acoustic analysis

The disyllables that were identified by the procedure described above were analysed acoustically for the prosodic cues which are relevant to the perception of syllable prominence, duration, intensity and f0. The acoustic analyses were carried out by means of a PRAAT script (Boersma & Weenink, 2014). Each of the three acoustic parameters was measured in the vowels of the disyllables only, not the entire syllable. This was done to reduce potential effects of syllable composition on the measurements. Duration (in ms) was measured from the start to the end of each vowel. Intensity was measured in dB as the mean energy averaged over the total number of analysis frames in the vowel. F0 was determined by means of the PRAAT autocorrelation method and expressed in Hz as the mean f0 averaged over the total number of analysis frames in the vowel. Intensity and f0 were analysed by the PRAAT analysis settings adjusted to child speech, i.e. the f0 range was set at 150-800 Hz. As there is no gold standard procedure for f0 measurements in child speech we performed multiple analyses to test the robustness of the f0 range setting and reliability of automatic f0 measurements used in this study. These are provided under Supplementary material 1.

The intensity range was set at 0-100 dB. It should be mentioned that intensity measurements in general need to be treated with caution. Intensity is very sensitive to background noise and recording quality. Since participants in this study were highly mobile and clip-on microphones were not used, we controlled for possible problematic intensity values by applying rigid selection criteria, cleaning the collected dataset for outliers and, most importantly, by computing the ratio between the intensity measurements of the two syllables. Ratio measures have been used in other studies relying on acoustic (Shriberg, Campbell, Karlsson, Brown, McSweeny, & Nadler, 2003) and kinematic (Goffman, 1999) analyses of prosodic modulation**.** The purpose of this study was to investigate the acoustic differentiation between syllables of

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utterances. Therefore, a ratio between the measurements in each syllable was computed to quantify this differentiation (i.e. durationV1/durationV2 and intensityV1/intensityV2). This also had the effect of normalising the intensity in louder utterances. The direction of the prosodic differentiation is contained in the ratio: a trochaic tendency is a ratio above one and an iambic tendency is a ratio below one. The perceptual f0 distance between the first and the second vowel in each disyllable was calculated by means of the formula $|39{,}86\ log10(f0V2/f0V1)|$. The absolute pitch distance specifies the perceptual distance in semitones between the first and the second vowel in each disyllable. For the pitch distance, the polarity of the signed value indicates the direction of the differentiation: a negative value represents a trochaic pattern whereas a positive number is an iambic pattern.

The final dataset consisted of 1151 disyllables of which 525 were babble and 626 were words (for numbers per participant, see Table II). The data were cleaned by means of the interquartile rule (IQR). This was done separately for every acoustic measurement, i.e. pitch distance, intensity ratio and duration ratio, and for babble and words separately. Per measurement, every value above or below the IQR threshold was identified as an outlier and excluded from the statistical analysis. For pitch distance, 4.1% of the disyllables were considered outliers, and 1103 utterances were included in the statistical analysis. For intensity ratios, 5.7% of the disyllables were outliers, and 1085 utterances were statistically analysed. For duration ratios, 0.01% of the utterances were outliers, and 1139 utterances were analysed. Utterances excluded for one of the three cues were not necessarily outliers for the other cues.

Statistical approach

Linear mixed models (LMM) were used for the data analysis (Baayen, 2008). LMM are particularly suited for analysing longitudinal corpus data because of their hierarchical structure: the observations (n = 1151) are measured at different time points embedded in different

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participants (n = 9). Moreover, linear mixed models are robust to missing and unequal numbers of observations for participants and time points. Importantly, when examining the effects of independent variables LMM take into account variation at the participant level as well as variation over time.

The analyses were carried out in R (R Core Team, 2013) using the lme4 package (Bates, Maechler, Bolker, & Walker, 2014) to generate models for the ratio of each prosodic cue. Each model consisted of random and fixed effects. In all analyses, the random effects? provided random intercepts and slopes for each individual and the age points within individuals. The fixed effects that were added to each model depended on the research question addressed by the analysis and are clarified in the next paragraphs. The statistical procedure consisted of two phases. A hierarchical approach was taken to build the models; the random and fixed effects were added one by one. At each step, a likelihood ratio test was carried out to arrive at the best-fitting model for the data, i.e. the model explaining the largest amount of variance with the fewest predictors. In the second phase, we took the best-fitting model and checked which effects were significant predictors. The estimates (henceforth E), standard errors (S.E.), t- and p-values of the fixed effects of the best-fitting models are reported in the results section.

The first research question concerned the effect of age and utterance type (i.e. babble or word) on the three acoustic cues. Therefore these predictors and their interactions were entered as fixed effects in the first set of analyses. For all models, age squared was added to test for non-linear development, but since this effect never significantly improved the fit of the models it will not be reported. The second research question concerned the effect of vocabulary size on the realisation of the three cues. Therefore a second set of analyses with cumulative vocabulary as a fixed effect was conducted on the lexical utterances only (n = 626) for each of the acoustic cues. Again, the random effects provided random intercepts and slopes for each individual and the

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developmental points within individuals.

However, since age and cumulative vocabulary were highly correlated in our dataset (the Pearson's correlation coefficient $r = 0.81$, $p < 0.001$), the possible vocabulary effect will be linked to increasing age. The best-fitting model with vocabulary as fixed effect and the best-fitting model with age as fixed effect were compared by inspecting the residual variances. All models with cumulative vocabulary as a longitudinal predictor had the lowest residual variances and were therefore deemed the most explanatory. Therefore only these models will be reported in the results section (The output of all models is provided in the Supplementary materials 5 to 10). In the build-up of the models, cumulative vocabulary squared was added, but as this never significantly improved the fit it will not be reported further.

Results

Table III summarises all three measurements per subject and utterance type.

INSERT TABLE III. and FIGURE 2 ABOUT HERE

Analysis 1: prosodic differentiation in babble and words

Fundamental frequency. For pitch distance, the absolute pitch distances (i.e. the unsigned value of the distance score between syllable 1 and syllable 2) were entered into the model. The best fitting model consisted of the fixed effects of age and utterance type (babble or word). The results are displayed in Figure 2 and the output of the statistical model is provided in Supplementary material 2. The estimate of the intercept was 3.261 (*S.E.* = 0.236, $t = 13.769$, $p < 0.001$), with 'words' as reference level for the factor of utterance type. The fixed effect of age showed no significant development over time ($E = 0.045$, *S.E.* = 0.028, $t = 1.593$, $p = 0.127$), indicating that pitch distance did not increase in older infants. However, there was a significant effect of utterance type on pitch distance ($E = -0.694$, *S.E.* = 0.197, $t = -3.529$, $p < 0.001$); this fixed effect indicates that the pitch distance was substantially larger in words than in babble. If we were

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furthermore interested in the type of stress pattern, the polarity of the signed pitch distance numbers need to be taken into account. Negative pitch distances indicate higher pitch on the first syllable (i.e. a trochaic tendency); positive pitch distances imply higher pitch on the second syllable (i.e. a iambic tendency). Table III shows the descriptive statistics that ascertain the type of stress pattern. Since no inferential statistics were performed on the stress pattern, these findings should be interpreted cautiously. The values in Table III show that a trochaic tendency is apparent in the babble of 6 out of 9 infants and is boosted towards an even stronger trochaic tendency in the words of 8 infants, as signed pitch distance values became more negative. Only participant 6 did not expand the differentiation towards a trochaic pattern. This might be due to the limited lexical utterances for this participant (n = 14, see Table II).

In answer to research question one, pitch distance on words was thus greater than on babble and negative polarity suggested a trochaic pattern on words which was already partly evident in babble.

Intensity. As for fundamental frequency, the best-fitting model for intensity had age and utterance type as fixed effects in the statistical model (see Supplementary material 3). The estimate of the intercept was 1.030 (*S.E.* = 0.009, $t = 115.786$, $p < 0.001$), again with 'words' as the reference level for the factor of utterance type. Although the fixed effect of age significantly improved the fit of the model, the effect itself was not significant, indicating hardly any development over time ($E = 0.001$, *S.E.* = 0.001, $t = 0.809$, $p = .427$). However, the fixed effect of utterance type ($E = -0.016$, *S.E.* = 0.007, $t = -2.183$, $p = .029$) suggests that intensity was not used to the same extent for babble and lexical material, with Figure 2 confirming that the intensity ratio was smaller in babble. In addition, the mean intensity ratios of babble and words were above or around 1, indicating a tendency towards a trochaic pattern (see Table III). This was confirmed in the words of all 9 participants and in the babble of 6 subjects, as can be seen in the individual data. Thus, in relation to the first research question, words showed increased amplitude

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modulation in comparison to babble, with the direction of modulation consistent with a trochaic prosodic structure.

Duration. The best statistical model for duration included utterance type and the interaction between age and utterance type as fixed effects in the statistical model (see Supplementary material 4). The estimate of the intercept was 0.856 (*S.E.* = 0.055, $t = 15.678$, $p < 0.001$), with 'words' as reference for the factor of utterance type, as above. There was a significant interaction effect between utterance type and age ($E = -0.037$, *S.E.* = 0.010, $t = -3.790$, $p < 0.001$), indicating that the ratios increased in the words with age. Since the estimate for the duration ratio was smaller than one, an increased ratio over time indicates a decrease in differentiation between syllables, i.e. a trend towards more even-timed syllables in words. The significant effect of age ($E = 0.037$, *S.E.* = 0.009, $t = 3.920$, $p < 0.001$), irrespective of utterance type, is likely to be driven by the ratio increase on the lexical utterances, since the slope for babble is flat (see Figure 2). Indeed, utterance type was also a significant effect, since babble overall had smaller duration ratios than did lexical utterances ($E = -0.126$, *S.E.* = 0.48, $t = -2.614$, $p = 0.009$) indicating a bigger durational contrast between syllables in babble than in words.

The mean durational ratios were below one (see Table III), indicating that the second syllable was longer than the first in both babble and words. On the surface, this pattern is more suggestive of an iambic acoustic pattern, although final lengthening effects cannot be ruled out (Sluijter & Van Heuven, 1995). The individual data confirm this tendency. Interestingly, the ratios on words grew closer to one, which indicates that the second syllable became shorter in words compared to babble, and that the syllables were less differentiated in terms of length. Therefore, in respect to research question one, duration differences between syllables actually lessened on words in comparison to babble, though the trochaic pattern was not evident in either words or babble.

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Analysis 2: the effect of cumulative vocabulary on lexical utterances

The first set of analyses showed a significant effect of utterance type on all three correlates of stress, with words having greater differentiation than babble in terms of f0 and intensity, and less differentiation for duration. Even the babble produced during the lexical period differed significantly from the lexical utterances produced at the same time in development. Consequently, the question arose whether these changes were systemic, i.e. whether the expansion of the lexicon enabled infants to produce finer and more controlled phonetic structures, or whether instead the intrinsic lexical nature of these utterances caused this development. Therefore, we examined whether the increasing cumulative vocabulary had an effect on the acoustic correlates of stress in lexical utterances.

Fundamental frequency and intensity. Comparable results were obtained for pitch and intensity. The only fixed effect in both analyses was cumulative vocabulary. The estimate of the intercept for pitch was 2.943 (*S.E.* = 0.323, $t = 9.109$, $p < 0.001$). For intensity this was 1.029 (*S.E.* = 0.011, $t = 90.643$, $p < 0.001$). Both for pitch ($E = 0.002$, *S.E.* = 0.003, $t = 0.785$, $p = 0.454$) and intensity ($E = 0.000$, *S.E.* = 0.000, $t = 0.094$, $p = 0.928$) there was no significant effect of cumulative vocabulary on the prosodic differentiation (see Supplementary material 5 and 7). This indicates that there was no gradual increase in prosodic differentiation between syllables as infants acquired a larger vocabulary. In answer to the second research question, neither pitch distance nor intensity were predicted by infants' vocabulary sizes.

Duration. For duration, the construction of the best models was the same as for fundamental frequency and intensity. The estimate of the intercept was 0.648 (*S.E.* = 0.049, $t = 13.349$, $p < 0.001$). However, the results for this cue were different: the analysis showed a significant effect of increasing cumulative vocabulary ($E = 0.001$, *S.E.* = 0.000, $t = 3.159$, $p = 0.016$) on duration ratios (see Supplementary material 9). In response to the second research

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question, it thus seems that vocabulary level has an effect on prosodic differentiation between syllables in terms of duration: the more words infants acquire, the more the ratios tend towards one (see Table III), indicating a tendency towards a more equally stressed acoustic pattern.

Discussion

This study examined the development of prominence production in the spontaneous babble and words of 9 typically developing infants acquiring Dutch. Two research questions were addressed: firstly, we explored whether there was a difference between babble and words regarding the production of fundamental frequency, intensity and duration in differentiating between syllables. Furthermore, it was investigated whether an influence of the ambient trochaic stress pattern would be evident in either the babble or words of the infants. The second point of interest concerned the impact of vocabulary acquisition, i.e. whether there was an effect of vocabulary size on the realisation of the cues to prosodic prominence in words. In discussing the present findings, it should be borne in mind that 9 infants make up a limited population sample, and that further studies would strengthen the present claims. Nevertheless, the substantial size of the dataset allowed us to report findings that were robust to variation from individual participants (see Table II).

Regarding the first research question, the analyses showed similar findings for f0 and intensity in that age did not have a significant impact, whereas utterance type did: the difference in f0 and intensity between syllables was significantly larger in words than in babble. Age was not a determining factor in prosodic development, whereas prosodic prominence was more contrastive in lexical disyllables than in babble. If the advent of vocabulary exerted an influence on babble, we should see a concomitant increase in the regression lines for babble. However, this was not the case as regression lines stayed remarkably flat even once vocabulary disyllables appeared. On words, first syllables typically received higher f0 and intensity than second

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syllables and this trochaic pattern is in keeping with the predominant stress pattern in Dutch (Cutler, 2005; Daelemans et al., 1994; Schiller et al., 1996). Although the acoustic signature of a trochaic pattern is present, it is not known whether adults also perceive this pattern as trochaic, and this will be investigated in future research. Moreover, as pointed out in the results section, we only consider descriptive statistics to ascertain the type of stress pattern. These findings should therefore be interpreted cautiously.

Intriguingly, the results for pitch difference and intensity ratio seem to suggest subtle traces of the trochaic pattern in the babbling stage, although this tendency is smaller than in words, both in terms of signed pitch distance and in the number of children who display it. Again, the perceptual effect of these measurements is unclear, but the descriptive statistics indicate that a trochaic pattern is potentially present at this early stage. The present results on babble as well as the ambiguous results on language-specific stress patterns reported by Davis et al. (2000) and DePaolis et al. (2008) are reminiscent of the concept of covert contrasts in child phonology. A child is said to have a COVERT CONTRAST between two phonemes when small acoustic differences can be detected, e.g. VOT differences for /b/ and /p/, which are not perceivable by adult listeners (Macken & Barton, 1980; Gierut & Dinnsen, 1986). The pattern in the data of the present study could similarly signal the beginning of language structure, which gradually emerges through fine phonetics for the majority of the infants. Since this is such a subtle phenomenon, a fairly large dataset might be required to detect it. Previous studies have used relatively small datasets: Davis et al. (2000) had 162 babble and DePaolis et al. (2008) analysed 687 disyllables distributed over four languages. The present study measured prosody in 525 babble and 626 words; by virtue of this large number of observations it may have been possible to observe this broad tendency in the phonetic system that had gone unnoticed so far. Alternatively, Goffman (1999) has suggested that children initially produce trochees by falling back on a motoric default which emerges during canonical babble. In order to disentangle motoric from linguistic influences, similar studies

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should be carried out with languages which have an iambic default stress pattern, such as Hebrew (Segal, Nir-Sagiv, Kishon-Rabin, & Ravid, 2009) to name but one.

For duration, the results were somewhat different. Whilst there was a clear effect of lexical status on duration, in that there was a decrease in durational contrast on words, the data also show that the second syllable was longer in both babble and words. The overall longer second syllable appears to contradict the findings for f0 and intensity and seems to go against the trochaic tendency in Dutch. However, it should be recalled that for duration, it is unclear exactly which aspect of prosody is being tapped: since these are isolated disyllables, they are also utterance-final, which means that they are subject to prosodic lengthening effects (White & Turk, 2010), and we are therefore unable to dissociate the effect of emerging word stress from utterance final lengthening. A comparison between words which have an iambic target in the adult lexicon and those with a trochaic target would have shed further light on the control of duration for word stress marking, but infants produced too few iambic target words to allow meaningful statistical analyses to be made. For the duration ratios, there was an effect of age, and a significant interaction between age and lexical status, suggesting that age had a different effect in babble and words. When considering the slopes for the development of duration in Figure 2 it appears that the significance of the age effect is caused by words alone, as the slope for babble is again virtually flat.

Interestingly, the duration ratio closer to one on words points to the fact that there is less modulation between the syllables in words than in babble, i.e. there was a reduction in the final lengthening effect on words, leading to a more even-timed pattern. The question that follows is whether this trend is a step towards the adult language or not. On the one hand, metrical theories such as the Trochaic/Iambic law (Hayes, 1985) claim that trochaic feet are marked with no durational contrast: the head and the tail of a trochee have even duration. Hence, final

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lengthening applied to a weak syllable might give the appearance of an unmodulated syllable. It might thus be the case that the words of the infants in the present study show this adult trend.

In contrast, Snow (1994) states that isochrony in stress production signals a period of reorganisation. In his study of durational and intonational abilities, he described less modulation at the transition from single to multiword utterances than?. Infants displayed adult-like final lengthening on their first words, before regressing to more equally-timed syllables between the single and multiword stage and eventually reverted to final lengthening once they were fully established in the multiword period. Snow (1994) suggested that two different mechanisms were at the root of the early and later abilities: physiological constraints (Lieberman, 1984; Robb & Saxman, 1990) are thought to underlie the first stage, and volitional, linguistic control over final lengthening is only evident once the child has entered the stage of combining words. The intervening period of relative isochrony signals a period of reorganisation, where the emerging word-combinations prompt children to actively try to control duration in utterances. As this skill is not yet acquired, and has to be integrated with nascent word combination, children temporarily fall back on rhythmic simplification. In the data of the present study, the shift towards more even-timed syllables in words may represent a similar process at the transition from babble to first words: the effort of producing an utterance which has an adult phonetic target and is semantically and pragmatically appropriate for the context may put enough pressure on the infant's language processing to trigger rhythmic simplification. However, since our data also encompass measurements at the transition to the multiword stage (Bates & Goodman, 1997; Devescovi, Caselli, Marchione, Pasqualetti, Reilly, & Bates, 2005), the loss of final lengthening may partly be driven by utterances measured at this stage. Future research may therefore attempt to disentangle the effects of the transition from babble to words and single words to multiwords on durational phenomena in child speech.

In summary, regarding the first research question, it can be concluded that the arrival of

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first words does indeed represent a marked transition in the ability to render prosodic differences between syllables: all three cues changed with the advent of first words, i.e. the f0 and intensity distinction between syllables became significantly larger, and there was a significant reduction of utterance final lengthening towards a more evenly-timed pattern in words. Moreover, the influence of the ambient trochaic stress pattern was reflected in mean f0 and intensity, possibly already at the babbling stage. Utterance-final lengthening appeared to be present in babble and reduced significantly with age on first words. A discontinuity in phonetic learning due to the emergence of vocabulary has been described for the segmental domain by Vihman and colleagues (Vihman & Velleman, 2000; Vihman & Kunnari, 2006). In their surface form, Welsh and Finnish share long medial consonants. In Welsh, these are due to accentual lengthening, in Finnish, long and short consonants have a lexical function as they distinguish words. At the 4-word point, Welsh and Finnish infants produced long medial consonants. By the 25-word point Finnish infants approximated the adult bimodal distribution, whereas the productions of Welsh infants did not show development. The authors concluded that lexical learning seemed to provide a further basis for pattern induction (Vihman & Kunnari, 2006: 158), and we would like to extend their proposal to the prosodic domain.

The second research question concerned the nature of the influence of the vocabulary. To address this, lexical disyllables were analysed separately, and we examined whether cumulative vocabulary or age were significant predictors for each cue. Analyses were also carried out with age squared and cumulative vocabulary squared as predictors to test for non-linear development. For f0 and intensity, none of these predictors were significant, suggesting that vocabulary size does not influence use of these cues. Vocabulary size was however a significant predictor for duration, and it provided a model with a significantly better fit for the data than age. This indicated that an increase in vocabulary size brought about reduced final lengthening independently of chronological age. This may be consistent with Snow (1994), as bigger

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vocabulary sizes are also more likely to be associated with the appearance of word combinations (Bates & Goodman, 1997; Devescovi et al., 2005). The fact that results on the role of vocabulary size dissociate between f0 and intensity on the one hand and duration on the other lends further support to the idea that the three cues are tapping different levels of prosody (Sluijter & van Heuven, 1995).

There was no impact of cumulative vocabulary size on f0 and intensity, although a link would be predicted by lexicalist theories of phonetic development which rely purely on frequency effects and strength of associations. If it were a question of needing a critical mass of vocabulary items before change can take place (Vihman & Velleman, 1989; Walley, 1993) we should see an effect for age squared, which signals non-linear development. Instead it seems that by virtue of being lexical items, disyllables become prosodically more distinct. Unlike babble, lexical disyllables have a clear adult model and a communicative function, although babble can be communicative too in a more global way (Stoel-Gammon & Cooper, 1984). In agreement with Vihman and colleagues (Vihman & Velleman, 2000; Vihman & Kunnari, 2006), it is further proposed that the linguistic nature of words causes infants to pay greater attention to phonetic detail and to consolidate representations. This is backed by a number of findings in different domains: in speech perception, a similar refinement of phonetic learning in words has been described. Yeung and Werker (2009) showed that nine-month-old infants were able to discriminate a non-native phonetic contrast if the training phase used the contrast in a meaningful way: if syllables differing by the relevant contrast were consistently used with two different objects, the infants, who had not been able to discriminate the contrast before training, were able to do so after. If, however, the training phase randomly assigned different syllables to the two objects, infants did not succeed at test. Therefore, a labeling function appears to aid phonetic perception. Further support comes from Swingley (2009) who suggested that a small proto-lexicon may help infants in the acquisition of phonetics by making boundaries between phonetic

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categories more evident. Crucially, it was hypothesised that this mechanism may be more efficient with a smaller than a larger vocabulary, as a small vocabulary results in clearer boundaries between phonetic categories. Feldman, Griffiths, and Morgan (2009) explored this idea by simulating lexically-constrained phonetic category learning. They reported better category distinction for a Bayesian model which incorporated some lexical knowledge than a more classical model (see e.g. Maye, Werker, & Gerken, 2002), which only computed categories from the distributional properties of the acoustic space. Finally, in the speech-motor domain, the impact of lexical status on articulatory stability has been examined experimentally in four- to six-year-old children (Heisler, Goffman, & Younger, 2010). In a fast-mapping task, children's repetitions had greater kinematic stability when a nonsense string was presented with a visual referent than without. It should be noted that this task did not incorporate a communicative function, suggesting that lexicalisation alone was sufficient to stabilise motor patterns in these older children.

We agree with lexicalist accounts that the size of the vocabulary has a prominent role to play in phonetic and phonological development, but it is suggested that this may become more important at later stages of language development. Instead, we propose that for the early stages investigated in the present study, the role of vocabulary development may be somewhat different, in that the function of first words for prosody production is similar to the highlighting effect on phonetic perception suggested by Werker, Yeung, and Yoshida (2012). Furthermore, this can be seen as analogous to work showing that language, and in particular labels, have a facilitatory effect on visual category formation (Waxman & Markow, 1995) and can even influence looking behaviour towards objects (Althaus & Marechal, 2014). In the same manner, the emergence of true linguistic behaviour brings about a re-organisation and refinement of prosodic phonetics.

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In conclusion, it can be said that traces of the ambient trochaic stress pattern are already present in the babble of Belgian-Dutch learning infants, which was only observable by virtue of a substantial dataset. Vocabulary items bring about an abrupt transition: f0 and intensity increase significantly, and the control of durational aspects appears to change. The increase in f0 and intensity differentiation is not related to vocabulary size, and therefore accounts which only rely on frequency or practice effects may not be appropriate for the emergence of early prominence marking. Instead, the communicative and linguistic nature of first words engenders phonetic enhancement.

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References

Althaus, N., & Marechal, D. (2014). Labels direct infants' attention to commonalities during novel category learning. *PLoS ONE, **9**: e99670.*

Baayen, H. (2008). *Analyzing linguistic data: a practical introduction to statistics*. Cambridge: Cambridge University Press.

Bates, D., Maechler, M., Bolker, B. M. , & Walker, S. (2014). lme4: linear mixed-effects models using Eigen and S4. R package version 1.1-7. Retrieved from http://CRAN.R-project.org/package=lme4.

Bates, E., & Goodman, J. (1997). On the inseparability of grammar and the lexicon: evidence from acquisition, aphasia and real-time processing. *Language and Cognitive Processes, **12***, 507-584.

Boersma, P., & Weenink, D. (2014). Praat: doing phonetics by computer. 5.4. Retrieved 5 October, 2014, from http://www.praat.org.

Brentari, D. (1998). *A prosodic model of sign language phonology*. Cambridge, MA: MIT Press.

Chapman, K. L., Hardin-Jones, M., Schulte, J., & Halter, K. A. (2001). Vocal development of 9-month-old babies with cleft palate. *Journal of Speech, Language, and Hearing Research, **44**,* 1268-1283.

Cruttenden, A. (1986). *Intonation*. Cambridge: Cambridge University Press.

Cutler, A. (2005). Lexical stress. In D. Pisoni & R. Remez (Eds.), *The handbook of speech perception* (pp. 264-289). Oxford: Blackwell.

Daelemans, W., Gillis, S., & Durieux, G. (1994). The acquisition of stress: a data-oriented approach. *Computational Linguistics, **20***, 421-451.

Davis, B., MacNeilage, P., Matyear, C., & Powell, J. (2000). Prosodic correlates of stress in babbling: an acoustical study. *Child Development, **71***, 1258-1270.

For Peer Review

DePaolis, R. A., Vihman, M. , & Kunnari, S. (2008). Prosody in production at the onset of word use: a cross-linguistic study. *Journal of Phonetics, **36***, 406-422.

Devescovi, A., Caselli, M., Marchione, D., Pasqualetti, P., Reilly, J., & Bates, E. (2005). A crosslinguistic study of the relationship between grammar and lexical development. *Journal of Child Language, **32***, 759-786.

Dupoux, E., Sebastian-Galles, N., Navarrete, E., & Peperkamp, S. (2008). Persistent stress 'deafness': the case of French learners of Spanish. *Cognition, **106***, 682-706.

Edwards, J., Beckman, M., & Munson, B. (2004). The interaction between vocabulary size and phonotactic probability effects on children's production accuracy and fluency in nonword repetition. *Journal of Speech, Language, and Hearing Research, **47***, 421-436.

Edwards, J., Munson, B., & Beckman, M. (2011). Lexicon-phonology relationships and dynamics of early language development - a commentary on Stoel-Gammon's 'Relationships between lexical and phonological development in young children'. *Journal of Child Language, **38***, 35-40.

Feldman, N. H., Griffiths, T. L., & Morgan, J. L. (2009). Learning phonetic categories by learning a lexicon. In N. A. Taatgen & H. van Rijn (Eds.), *Proceedings of the 31st Annual Conference of the Cognitive Science Society* (pp. 2208-2213). Austin, TX: Cognitive Science Society.

Free-Video-Converter (Version 2.1.0). (2012): QIXINGSHI TECHNOLOGY.

Friederici, A., Friedrich, M., & Christophe, A. (2007). Brain responses in 4-month-old infants are already language specific. *Current Biology, **17***, 1208-1211.

Gierut, J. A., & Dinnsen, D. A. (1986). On word-initial voicing. Converging sources of evidence in phonologically disordered speech. *Language and Speech, **29***, 97-114.

Goffman, L. (1999). Prosodic influences on speech production in children with specific language impairment and speech deficits. *Journal of Speech Language and Hearing Research*, **42**,

For Peer Review

1499-1517.

Hallé, P., De Boysson-Bardies, B., & Vihman, M. (1991). Beginnings of prosodic organization: intonation and duration patterns of disyllables produced by Japanese and French infants. *Language and Speech, **34***, 299-318.

Hayes, B. (1985). Iambic and trochaic rhythm in stress rules. *Proceedings of the Annual Meeting, Berkeley Linguistics Society,* **11**, 429–446.

Heisler, L., Goffman, L., & Younger, B. (2010). Lexical and articulatory interactions in children's language production. *Developmental Science, **13***, 722-730.

Huttenlocher, J., Haight, W., Bryk, A., Seltzer, M., & Lyons, T. (1991). Early vocabulary growth: relation to language input and gender. *Developmental Psychology*, **27**, 236-248.

Jusczyk, P., Cutler, A., & Redanz, N. (1993). Infants' preference for the predominant stress patterns of English words. *Child Development, **64***, 675-687.

Kochanski, G., Grabe, E., Coleman, J., & Rosner, B. (2005). Loudness predicts prominence: fundamental frequency lends little. *Journal of the Acoustical Society of America, **118***, 1038-1054.

Lieberman, P. (1960). Some acoustic correlates of word stress in American English. *Journal of the Acoustical Society of America, **32***, 451-454.

Lieberman, P. (1984). *The biology and evolution of language.* Cambridge: Harvard University Press.

Macken, M., & Barton, D. (1980). Acquisition of the voicing contrast in English. A study of voice onset time in word-initial stop consonants. *Journal of Child Language, **7***, 41-74.

MacWhinney, B. (2000). The CHILDES Project: Tools for Analyzing Talk. 3rd Edition. Mahwah, NJ: Lawrence Erlbaum Associates

MacWhinney, B. (2013). CLAN (Version 04-Nov-2013 11:00).

Maye, J., Werker, J., & Gerken, L. (2002). Infant sensitivity to distributional information can

For Peer Review

affect phonetic discrimination. *Cognition,* ***82***, B101-B111.

Molemans, I., van den Berg, R., Van Severen, L., & Gillis, S. (2012). How to measure the onset of babbling reliably? *Journal of Child Language*, ***39***, 523-552.

Munson, B. (2001). Phonological pattern frequency and speech production in adults and children. *Journal of Speech, Language, and Hearing Research,* ***44***, 778-792.

Nespor, M., Shukla, M., van de Vijver, R., Avesani, C., Schraudolf, H., & Donati, C. (2008). Different phrasal prominence realization in VO and OV languages. *Lingue e Linguaggio,* ***7***, 1-28.

Nespor, M., & Vogel, I. (1986). *Prosodic phonology*. Dordrecht: Foris.

Oller, D. (1973). The effect of position-in-utterance on speech segment duration in English. *Journal of the Acoustical Society of America,* ***54***, 1235-1247.

Pierrehumbert, J. (2003). Phonetic diversity, statistical learning, and acquisition of phonology. *Language and Speech,* ***46***, 115-154.

Robb, M., & Saxman, J. (1990). Syllable durations of preword and early word vocalizations. *Journal of Speech and Hearing Research,* ***33***(3), 583-593.

Sansavini, A., Bertoncini, J., & Giovanelli, G. (1997). Newborns discriminate the rhythm of multisyllabic stressed words. *Developmental Psychology,* ***33***, 3-11.

Schiller, N., Meyer, A., Baayen, H., & Levelt, W. (1996). A comparison of lexeme and speech syllables in Dutch. *Journal of Quantitative Linguistics,* ***3***, 8-28.

Shriberg, L. D., Campbell, T. F., Karlsson, H. B., Brown, R. L., McSweeny, J. L., & Nadler, C. J. (2003). A diagnostic marker for childhood apraxia of speech: the lexical stress ratio. *Clinical Linguistics and Phonetics*, **17**, 549-574.

Segal, O., Nir-Sagiv, B., Kishon-Rabin, L., & Ravid, D. (2009). Prosodic patterns in Hebrew child-directed speech. *Journal of Child Language,* ***36***, 629-656.

Selkirk, E. (1984). *Phonology and syntax. The relation between sound and structure*. Cambridge,

For Peer Review

MA: MIT Press.

Skoruppa, K., Pons, F., Christophe, A., Bosch, L., Dupoux, E., Sebastian-Galles, N., Limissuri, R.A., Peperkamp, S. (2009). Language-specific stress perception by 9-month-old French and Spanish infants. *Developmental Science, **12***, 914-919.

Sluijter, A., & van Heuven, V. (1995). Effects of focus distribution, pitch accent and lexical stress on the temporal organization of syllables in Dutch. *Phonetica, **52***, 71-89.

Snow, D. (1994). Phrase-final syllable lengthening and intonation in early child speech. *Journal of Speech and Hearing Research, **37***, 831-840.

Stoel-Gammon, C. (2011). Relationships between lexical and phonological development in young children. *Journal of Child Language, **38***, 1-34.

Stoel-Gammon, C., & Cooper, J. (1984). Patterns of early lexical and phonological development. *Journal of Child Language, **11***, 247-271.

Storkel, H. L. (2001). Learning new words: phonotactic probability in language development. *Journal of Speech, Language, and Hearing Research*, **44**, 1321-1337.

Storkel, H. L. (2003). Learning new words II: phonotactic probability in verb learning. *Journal of Speech, Language, and Hearing Research*, **46**, 1312-1323.

Swingley, D. (2009). Contributions of infant word learning to language development. *Philosophical Transactions of The Royal Society B: Biological Sciences, **364***, 3617-3632.

Van Severen, L., Gillis, J., Molemans, I., van den Berg, R., De Maeyer, S., & Gillis, S. (2013). The relation between order of acquisition, segmental frequency and function: the case of word-initial consonants in Dutch. *Journal of Child Language*, **40**, 703-740.

Vanormelingen, L., De Maeyer, S., & Gillis, S. (2015). Interaction patterns of mothers of children with different degrees of hearing: normally hearing children and congenitally hearing-impaired children with a cochlear implant. *International Journal of Pediatric Otorhinolaryngology, **79***, 520-526.

For Peer Review

Verhoeven, J. (2005). Belgian Standard Dutch. *Journal of the International Phonetic Association, **35***, 243-247.

Vihman, M. (2009). Word learning and the origins of phonological systems. In S. Foster-Cohen (Ed.), *Language acquisition* (pp. 15-39). Basingstroke, Hampshire: Palgrave Macmillan.

Vihman, M., DePaolis, R., & Davis, B. (1998). Is there a "trochaic bias" in early word learning? Evidence from infant production in English and French. *Child Development, **69***, 935-949.

Vihman, M., & Kunnari, S. (2006). The sources of phonological knowledge: a cross-linguistic perspective. *Recherches Linguistiques de Vincennes, **35***, 133-164.

Vihman, M., & McCune, L. (1994). When is a word a word. *Journal of Child Language, **21***, 517-542.

Vihman, M., & Velleman, S. (1989). Phonological reorganization: a case study. *Language, Speech, and Hearing Services in Schools, **33***, 9-33.

Vihman, M. , & Velleman, S. (2000). The construction of a first phonology. *Phonetica, **57***, 255-266.

Walley, A. (1993). The role of vocabulary development in children's spoken word recognition and segmentation ability. *Developmental Review, **13***, 286-350.

Waxman, S., & Markow, D. (1995). Words as invitations to form categories: evidence from 12- to 13-month-old infants. *Cognitive Psychology, **29***, 527-302.

Werker, J., & Tees, R. (2005). Speech perception as a window for understanding plasticity and commitment, language systems of the brain. *Developmental Psychobiology, **46***, 233-251.

Werker, J., Yeung, H., & Yoshida, K. (2012). How do infants become experts at native-speech perception? *Current Directions in Psychological Science, **21***, 221-226.

White, L., & Turk, A. (2010). English words on the procrustean bed: polysyllabic shortening reconsidered. *Journal of Phonetics, **38***, 459-471.

Yeung, H., & Werker, J. (2009). Learning words' sounds before learning how words sound: 9-

For Peer Review

month-olds use distinct objects as cues to categorize speech information. *Cognition,* ***113***, 234-243.

Zink, I., & Lejaegere, M. (2001). *N-CDIs: lijsten voor communicanieve ontwikkeling. Aanpassing en hernormering van de MacArthur CDI's van Fenson et al.* Leuven: ACCO.

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Tables and figures

Table I.

Ages of the individual children at the time of recording.

Subject	Gender	Age start (y;mm.dd)	Age end (y;mm.dd)	# recordings	Onset word use (y;mm.dd)
1	M	0;06.03	2;00.01	19	1;02.09
2	M	0;06.29	2;00.02	18	1;00.01
3	M	0;06.00	1;11.05	19	1;01.31
4	M	0;05.27	1;11.30	19	1;00.30
5	F	0;06.03	1;11.29	19	0;11.00
6	M	0;06.05	2;00.04	19	1;03.30
7	F	0;07.02	1;11.27	18	1;04.02
8	F	0;06.04	2;00.04	19	1;00.05
9	F	0;08.02	1;09.28	15	1;03.00

Note. Age start = the onset of babbling

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Table II.

Number of selected disyllables per subject and utterance type (babble and lexical)

Subject	Babble	Lexical	Total
1	122	161	283
2	40	59	99
3	47	96	143
4	87	88	175
5	49	45	94
6	80	14	94
7	36	50	86
8	33	43	76
9	31	70	101
Total	**525**	**626**	**1151**
Mean	**58,33**	**69,56**	**127,89**
SD	**29,41**	**39,85**	**62,19**

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Table III.

Summary of the measurements per subject and utterance type (Babble and Lexical)

Subject	Utterance type	Signed pitch distance *Median (MAD)*	Absolute pitch distance *Mean (SD; range)*	Intensity ratio *Mean (SD; range)*	Duration Ratio *Mean (SD; range)*
1	Babble	-0,82 (2,04)	2,56 (1,91; 0,08-7,51)	1,01 (0,07; 0,84-1,20)	0,74 (0,40; 0,08-1,94)
	Lexcial	-3,03 (3,43)	4,17 (2,87; 0,07-10,51)	1,05 (0,09; 0,82-1,26)	0,98 (0,51; 0,16-2,34)
2	Babble	-0,84 (1,12)	1,61 (1,31; 0,08-5,32)	1,00 (0,08; 0,80-1,16)	0,83 (0,43; 0,15-1,88)
	Lexical	-1,05 (1,93)	2,47 (1,84; 0,01-8,64)	1,00 (0,07; 0,84-1,14)	0,80 (0,41; 0,19-1,84)
3	Babble	0,78 (2,03)	2,43 (1,89; 0,07-6,35)	1,00 (0,09; 0,83-1,22)	0,60 (0,34; 0,09-1,59)
	Lexical	-1,18 (1,93)	2,93 (2,49; 0,09-10,41)	1,02 (0,08; 0,84-1,16)	0,82 (0,42; 0,10-2,05)
4	Babble	-0,15 (1,44)	1,95 (1,61; 0,01-7,26)	1,01 (0,08; 0,81-1,15)	0,68 (0,36; 0,06-1,93)
	Lexical	-0,44 (3,19)	3,79 (2,54; 0,03-10,06)	1,01 (0,08; 0,82-1,22)	0,78 (0,39; 0,20-2,26)
5	Babble	-0,30 (2,25)	2,31 (1,92; 0,02-7,18)	0,99 (0,08; 0,81-1,19)	0,78 (0,41; 0,13-1,82)
	Lexical	-1,67 (2,31)	3,29 (2,47; 0,01-9,22)	1,02 (0,07; 0,86-1,18)	0,69 (0,37; 0,15-1,52)
6	Babble	0,49 (1,90)	2,24 (1,60; 0,24-7,00)	0,98 (0,08; 0,78-1,21)	0,57 (0,35; 0,11-1,89)
	Lexical	0,78 (1,66)	2,16 (1,89; 0,04-6,01)	1,03 (0,09; 0,86-1,21)	0,60 (0,36; 0,13-1,31)
7	Babble	0,07 (1,69)	1,94 (1,59; 0,07-6,59)	1,00 (0,08; 0,85-1,16)	0,74 (0,35; 0,07-1,19)
	Lexical	-3,10 (2,04)	3,98 (2,48; 0,06-9,28)	1,05 (0,06; 0,92-1,18)	0,75 (0,37; 0,19-1,79)
8	Babble	-1,10 (1,29)	1,69 (1,25; 0,01-5,05)	0,99 (0,09; 0,83-1,17)	0,54 (0,29; 0,15-1,38)
	Lexical	-1,98 (1,63)	2,74 (2,23; 0,15-10,38)	1,04 (0,09; 0,83-1,23)	0,78 (0,48; 0,08-1,94)
9	Babble	-0,98 (1,29)	1,91 (1,73; 0,26-6,13)	1,07 (0,11; 0,84-1,24)	0,99 (0,39; 0,47-1,90)
	Lexical	-2,13 (1,41)	2,81 (2,10; 0,00-10,33)	1,06 (0,07; 0,80-1,23)	1,05 (0,47; 0,32-2,28)
Total	**Babble**	**-0,36 (1,60)**	**2,17 (1,73)**	**1,01 (0,08)**	**0,70 (0,39)**
	Lexical	**-1,69 (2,42)**	**3,38 (2,54)**	**1,03 (0,08)**	**0,85 (0,46)**

Note. MAD = Median absolute deviation; SD = standard deviation; Pitch distance: negative value = trochaic pattern, positive value = iambic pattern; Intensity and duration ratio: Ratio > 1 = trochaic pattern, ratio < 1 = iambic pattern.

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Figure 1.

An annotated disyllabic word (auto, /ʌuto/, 'car') in PRAAT. The waveform (top) and spectrogram (bottom) were used to segment the speech stream.

Note. a = first syllable; b = second syllable; v = vowel; c = consonant

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Figure 2.

Scatterplots of the measurements for both lexical and babbled utterances.

Note. Shaded area = confidence interval

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Supplementary material

Supplementary material 1.

In order to determine the optimal procedure for f0 measurements in child speech we tested the robustness and reliability of the f0 range settings:

F0 range

A large f0 range might increase the risk for anomalous measurements. Therefore the entire dataset was re-analysed with a smaller pitch range of 400Hz (150-650Hz). A series of correlations and kappa scores were carried out on both sets of measurements, to see if the modification of the range could have impacted the findings of the study. The results were as follows:

The Pearson's product-moment correlation between the values reported in the present study (i.e. pitch range of 650 Hz) and the new values (i.e. pitch range of 400 Hz) was $r = 0.87$ ($p < .001$). To see whether pitch tracker settings could affect the descriptive statistics used to discuss the appearance of trochaic versus iambic pattern, the pitch distances were categorised into trochees (negative values) and iambs (positive values). The kappa coefficient between the old and new datasets was $k = 0.90$.

The high correlations between the reported measurements and the values obtained after narrowing the pitch range to 400 Hz, indicate that both sets of measurements yield highly similar results, which are unlikely to affect the main conclusions of the study.

Automatic measurements

Secondly we tested whether it is appropriate to use automatic measurements for child data without hand correction. This boils down to the question of how much noise this leaves in the data, and whether this can affect the statistical results. Therefore the pitch-tracking of all 1381 files of disyllabic utterances was visually re-inspected.

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(1) 127 files of 1381 were regarded potentially problematic on the basis of visual inspection. This amounts to 9,19 % of the entire dataset. Some of the problems had to do with previously unnoticed creaky voice, but also with segmental effects of the prevocalic consonant. In these potentially problematic files, pitch what re-measured manually.

(2) The correlation between the original dataset and the new dataset with hand measured pitch values was $r = 0.86$ ($p < .001$).

(3) We also converted the semitone measurements into a nominal expression of whether pitch was higher on the first or second syllable. When comparing the original and new dataset, kappa amounted to $k = 0.96$.

The high correlations between the automatic and hand corrected measurements, indicate that both sets of measurements yield highly similar results, which are unlikely to affect the main conclusions of the study.

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Supplementary material 2.

Statistical output for the pitch distance.

	Estimate	Standard Error	t	p
Intercept	3.261	0.236	13.796	< 0.001***
Age	0.045	0.028	1.593	0.127
Utterance type[Babble]	-0.694	0.197	-3.520	< 0.001***

Note. Utterance type = babble or word, with the reference category between []; ***: p ≤ '0.001', **: p ≤ '0.01', *: p ≤ '0.05', .: p ≤ '0.1'

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Supplementary material 3.

Statistical output for the intensity ratios.

	Estimate	Standard Error	t	p
Intercept	1.030	0.009	115.786	< 0.001 ***
Age	0.001	0.001	0.809	0.427
Utterance type[Babble]	-0.016	0.007	-2.183	0.029 *

Note. Utterance type = babble or word, with the reference category between []; ***: p ≤ '0.001', **: p ≤ '0.01', *: p ≤ '0.05', .: p ≤ '0.1'

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Supplementary material 4.

Statistical output for the duration ratios.

	Estimate	Standard Error	t	p
Intercept	0.856	0.055	15.678	< 0.001 ***
Age	0.037	0.009	3.920	< 0.001 ***
Utterance type[Babble]	-0.126	0.048	-2.614	< 0.009 **
Interaction: age*utterance type[age*Babble]	-0.037	0.010	-3.799	< 0.001 ***

Note. Utterance type = babble or word, with the reference category between []; ***: p ≤ '0.001', **: p ≤ '0.01', *: p ≤ '0.05', .: p ≤ '0.1'

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Supplementary material 5.

Statistical output for the pitch distance: analysis on lexical subset with cumulative vocabulary as longitudinal predictor.

	Estimate	Standard Error	t	p
Intercept	2.943	0.323	9.109	< 0.001***
Cumulative vocabulary	0.002	0.003	0.785	0.454

Note. ***: p ≤ '0.001', **: p ≤ '0.01', *: p ≤ '0.05', .: p ≤ '0.1'

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Supplementary material 6.

Statistical output for the pitch distance: analysis on lexical subset with chronological age as longitudinal predictor.

	Estimate	Standard Error	t	p
Intercept	3.254	0.264	12.315	< 0.001***
Age	0.042	0.076	0.552	0.591

Note. ***: p ≤ '0.001', **: p ≤ '0.01', *: p ≤ '0.05', .: p ≤ '0.1'

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Supplementary material 7.

Statistical output for the intensity ratios: analysis on lexical subset with cumulative vocabulary as longitudinal predictor.

	Estimate	Standard Error	t	p
Intercept	1.029	0.011	90.643	< 0.001***
Cumulative vocabulary	0.000	0.000	0.094	0.928

Note. ***: p ≤ '0.001', **: p ≤ '0.01', *: p ≤ '0.05', .: p ≤ '0.1'

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Supplementary material 8.

Statistical output for the intensity ratios: analysis on lexical subset with chronological age as longitudinal predictor.

	Estimate	Standard Error	t	p
Intercept	1.031	0.009	112.093	< 0.001***
Age	0.000	0.003	0.063	0.951

Note. ***: p ≤ '0.001', **: p ≤ '0.01', *: p ≤ '0.05', .: p ≤ '0.1'

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Supplementary material 9.

Statistical output for the duration ratios: analysis on lexical subset with cumulative vocabulary as longitudinal predictor.

	Estimate	Standard Error	t	p
Intercept	0.648	0.049	13.349	< 0.001***
Cumulative vocabulary	0.001	0.000	3.159	0.016 *

Note. ***: p ≤ '0.001', **: p ≤ '0.01', *: p ≤ '0.05', .: p ≤ '0.1'

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Supplementary material 10.

Statistical output for the duration ratios: analysis on lexical subset with chronological age as longitudinal predictor.

	Estimate	**Standard Error**	**t**	**p**
Intercept	0.858	0.067	12.843	< 0.001***
Age	0.033	0.015	2.204	0.047*

Note. ***: p ≤ '0.001', **: p ≤ '0.01, *: p ≤ '0.05', .: p ≤ '0.1'

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239.582524
0.5319
-0.003723
-0.5075
Channel 1
0.5319
-0.5075
Channel 2
5000 Hz
0 Hz
1
a
b
syll
(1/4)
2
v
c
v
word
(5)
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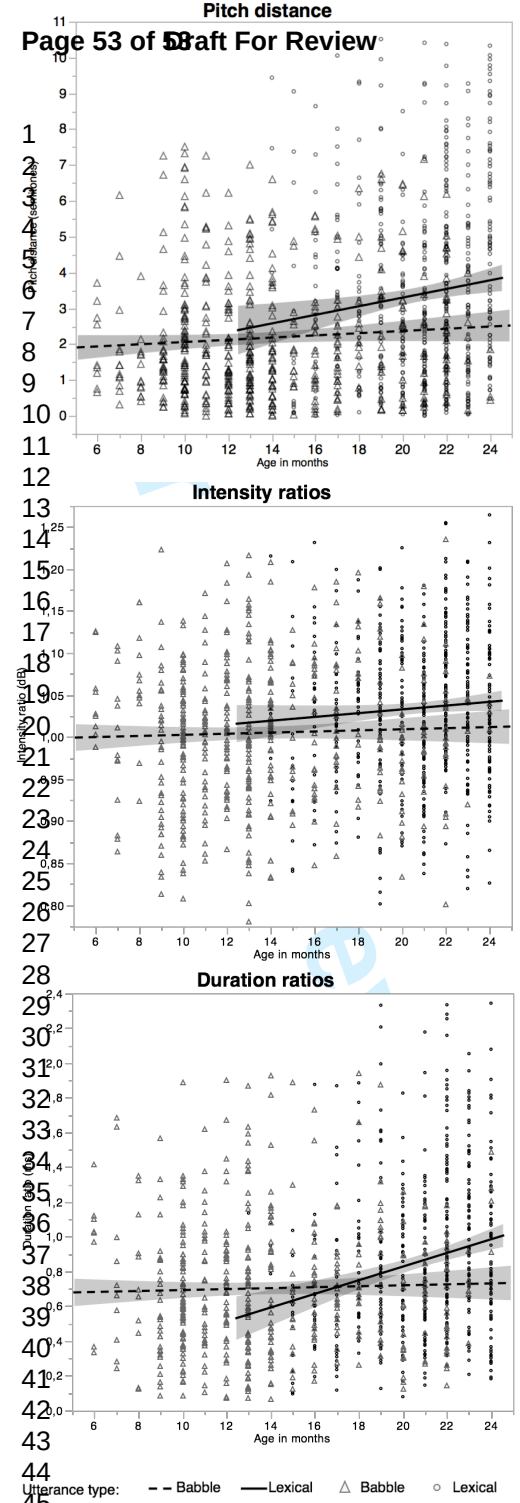
0.069118
Total duration 1.572000 seconds


Pitch distance
Pitch distance (semitones)
Age in months
Intensity ratios
Intensity ratio (dB)
Age in months
Duration ratios
Duration ratio (log)
Age in months
Utterance type:
Babble
Lexical
Babble
Lexical