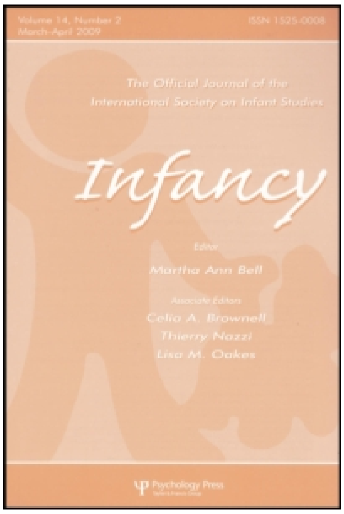


Infancy
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t775653654

Prosodic Structure in Early Word Segmentation: ERP Evidence From Dutch Ten-Month-Olds

Valesca Kooijman [abc]; Peter Hagoort [ab]; Anne Cutler [abd]
[a] Donders Institute for Brain, Cognition and Behavior, Radboud University, Nijmegen, The Netherlands [b] Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands [c] Top Institute Food & Nutrition, Wageningen, The Netherlands [d] MARCS Auditory Laboratories, University of Western Sydney, Australia

Online publication date: 19 November 2009

To cite this Article Kooijman, Valesca, Hagoort, Peter and Cutler, Anne(2009) 'Prosodic Structure in Early Word Segmentation: ERP Evidence From Dutch Ten-Month-Olds', Infancy, 14: 6, 591 — 612

To link to this Article: DOI: 10.1080/15250000903263957

URL: http://dx.doi.org/10.1080/15250000903263957

Infancy, *14*(6), 591–612, 2009

ISSN: 1525-0008 print / 1532-7078 online
DOI: 10.1080/15250000903263957

Psychology Press
Taylor & Francis Group

Prosodic Structure in Early Word Segmentation: ERP Evidence From Dutch Ten-Month-Olds

Valesca Kooijman
Donders Institute for Brain, Cognition and Behavior, Radboud University, Nijmegen, The Netherlands; Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands; and Top Institute Food & Nutrition, Wageningen, The Netherlands

Peter Hagoort
Donders Institute for Brain, Cognition and Behavior, Radboud University, Nijmegen, The Netherlands; and Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands

Anne Cutler
Donders Institute for Brain, Cognition and Behavior, Radboud University, Nijmegen, The Netherlands; Max Planck Institute for Psycholinguistics, Nijmegen, The Netherlands; and MARCS Auditory Laboratories, University of Western Sydney, Australia

Recognizing word boundaries in continuous speech requires detailed knowledge of the native language. In the first year of life, infants acquire considerable word segmentation abilities. Infants at this early stage in word segmentation rely to a large extent on the metrical pattern of their native language, at least in stress-based languages. In Dutch and English (both languages with a preferred trochaic stress pattern), segmentation of strong–weak words develops rapidly between 7 and 10 months of age. Nevertheless, trochaic languages contain not only strong–weak words but also words with a weak–strong stress pattern. In this article, we present

Correspondence should be addressed to Valesca Kooijman, Top Institute Food & Nutrition, P.O. Box 557, 6700 AN Wageningen, The Netherlands. E-mail: kooijman@tifn.nl

electrophysiological evidence of the beginnings of weak–strong word segmentation in Dutch 10-month-olds. At this age, the ability to combine different cues for efficient word segmentation does not yet seem to be completely developed. We provide evidence that Dutch infants still largely rely on strong syllables, even for the segmentation of weak–strong words.

Before their first birthday, infants learn to extract possible word forms from continuous speech. That is, before they can actually speak any words they learn how to find the boundaries between the words in the spoken language they hear. Finding the boundaries between words, or word segmentation, is vitally important for language development. The ability to segment is a good predictor of language skills at a later age (e.g., vocabulary size at age 2; Newman, Bernstein Ratner, Jusczyk, Jusczyk, & Dow, 2006).

In adults, word segmentation is well established; adults can make use of many segmentation cues that they know to be useful because they know the probabilities of their native language (e.g., prosodic cues: Cutler & Butterfield, 1992; phonotactics: McQueen, 1998). The effect of these cues is intensified in the large adult vocabulary (Norris, McQueen, & Cutler, 1995). Adults' segmentation cues appear to be hierarchically integrated, such that lexical cues are weighted higher in segmentation of English than prosodic cues, but flexible, so that when surrounding conditions are not optimal (e.g., in noise) the lower level prosodic cues can still drive segmentation (Mattys, White, & Melhorn, 2005).

Infants beginning to learn their native language, in contrast, as yet have no vocabulary, and hence cannot rely on lexical information (except maybe for highly frequent words, such as "mummy" and "daddy"; see Bortfeld, Morgan, Golinkoff, & Rathbun, 2005; Tincoff & Jusczyk, 1998). In addition, word boundaries correlate poorly with silent breaks in spoken language. Infants thus have to rely on cues in the sound structure of their native language, be they phonotactic (permissible phoneme order), phonetic (speech sound properties), or prosodic (e.g., the metrical stress pattern of a language). Unfortunately, these cues are probabilistic rather than all-or-none (Kuhl, 2004). Therefore, infants not only have to discover these separate cues, but also have to learn how to combine them to detect word boundaries efficiently. The task of learning to segment words from speech is thus not as easy as it might seem. Nevertheless, by about 10 months of age, infants are quite proficient at segmenting words—at least, words with a strong–weak stress pattern in trochaic stress-based languages (i.e., languages with a predominantly strong–weak stress pattern) such as Dutch and English (e.g., Jusczyk & Aslin, 1995; Kooijman, Hagoort, & Cutler, 2005; Kooijman, Johnson, & Cutler, 2008; see also Nazzi, Iakimova, Bertoncini, Frédonie, & Alcantara, 2006, for French).

A sensitivity to the metrical rhythm or stress pattern of the native language appears to play an important role in developing these segmentation skills. As early as 4 months of age, infants show a bias toward the predominant stress pattern of their native language (Friederici, Friedrich, & Christophe, 2007; Weber, Hahne, Friedrich, & Friederici, 2004). In the second half of the first year of life, English-learning infants prefer to listen to strong–weak words over weak–strong words (Jusczyk, Cutler, & Redanz, 1993), thus exhibiting a preference for the words that are more typical in their language. Infants acquiring English and Dutch can recognize words that conform to this pattern when they occur in the context of continuous speech (Houston, Santelmann, & Jusczyk, 2004; Jusczyk, 1999; Juszcyk, Houston, & Newsome, 1999; Mattys & Jusczyk, 2001; Nazzi, Dilley, Jusczyk, Shattuck-Hufnagel, & Jusczyk, 2005, for English; Kooijman, Hagoort, & Cutler, 2005; submitted; Kuijpers, Coolen, Houston, & Cutler, 1998, for Dutch; Houston, Jusczyk, Kuijpers, Coolen, & Cutler, 2000, for both).

At about 9 months of age, infants show further knowledge of the typical patterns of their native language by demonstrating sensitivity to phonotactic properties (Jusczyk, Friederici, Wessels, Svenkerud, & Jusczyk, 1993; Jusczyk, Luce, & Charles-Luce, 1994; Myers et al., 1996; Saffran, Aslin, & Newport, 1996). Nevertheless, the predominant stress pattern appears to be the preferred cue for some period of time during the development of segmentation skills. In a study using the headturn preference procedure (HPP), Mattys, Jusczyk, Luce, and Morgan (1999) presented 9-month-old English-learning infants with bisyllabic strings in which phonotactics indicated either that both syllables belonged to the same word (e.g., *nongkuth* where the sounds *–ng* and *k–* occur more often in sequence within words than across a word boundary) or to two words (e.g., *nongtuth* where the reverse probability holds). The infants showed a preference for strong–weak words with one-word phonotactics, but for weak–strong words with two-word phonotactics. Thus, 9-month-olds weight prosody highly; they perceive strong syllables as word-initial, and prefer the phonotactics corresponding to this. Next, Mattys et al. (1999) pitted the prosodic against the phonotactic cues by presenting the infants with strong–weak words with the two-word phonotactics, and with weak–strong words with the one-word phonotactics. Here the infants showed a preference for the strong–weak words in spite of the conflicting phonotactic information in these words; that is, again they weighted prosody most highly. Johnson and Jusczyk (2001) likewise pitted metrical stress patterns against statistical distribution of speech sounds. After familiarization with a stream of speech in an artificial language, English-learning 8-month-olds were tested on isolated "words" and part words with conflicting prosodic and phonotactic information. Once again, the infants weighted prosodic cues more heavily than phonotactic cues. Thiessen and Saffran (2003) similarly showed that 9-month-old infants used stress as a segmentation cue but ignored statistical information; in contrast, 7-month-olds tested on the same paradigm in their study attended more to the statistical than to the stress cues. Thus, these studies show that by 8 or 9 months of age, when vocabulary learning is due to begin, infants prefer stress cues for segmenting speech over alternatives such as phonotactics and distributional statistics.

This preference, however, could lead to missegmentation of some word types from continuous speech, in particular words with a weak–strong stress pattern. Metrical stress, like other possible segmentation cues, has a probabilistic nature, so that vocabularies contain both strong–weak and weak–strong words. The latter are in the minority, of course: Cutler and Carter (1987) found 17% initially weak words in a frequency-adjusted corpus of English, and 10% initially weak among the lexical words in a sample of natural English speech. In a corpus of Dutch, Van de Weijer (1998) found that 88.3% of the lexical words spoken to adults (and 97.2% of the lexical words directed at an infant) started with a strong syllable. Although the percentage of lexical words with an initial weak syllable is relatively low in English and Dutch, it still accounts for a considerable number of words. At some point infants have to learn to deal with these words with an initial weak syllable to efficiently segment all words from speech.

A few studies have addressed this issue. Jusczyk et al. (1999) ran an impressive series of HPP experiments to study weak–strong word segmentation in infants. They showed that English-learning 7.5-month-old infants are able to segment strong–weak words from speech, but not weak–strong words. However, 10.5-month-olds did segment the weak–strong words from speech. In addition, after familiarization with only the strong syllables of the weak–strong words (e.g., *tar* from *guitar*), they did not then show a preference for passages containing the whole weak–strong words, as the 7.5-month-old infants had. These results suggest that whereas 7.5-month-olds might be just segmenting the strong syllables from speech, the 10.5-month-olds do more than that. The authors concluded that at this later age, infants no longer rely solely on the stress pattern of their native language for word segmentation, but are able to combine multiple sources of information about likely word boundaries in speech, such as metrical stress and phonotactics (also see Morgan & Saffran, 1995). An HPP study by Johnson (2005) showed that English-learning 10.5-month-old infants' representations of weak–strong words are fairly detailed after familiarization, which suggests that they have a representation of the whole word, including the initial weak syllable.

Considering the high similarity between English and Dutch (both are trochaic stress-based languages), a comparable rate of development of word segmentation might be expected. However, English-learning infants show a behavioral preference for familiar strong–weak words in sentences at 7.5 months of age (Jusczyk, 1999; Mattys & Jusczyk, 2001), whereas Dutch infants do not show such a preference until 9 months of age, even in an experimental HPP paradigm that is the same as its English counterpart (except, of course, for the use of the Dutch language instead of English; Kuijpers et al., 1998). These studies suggest that Dutch infants might need slightly more time to acquire their metrically based segmentation skills. In part, this delay might be due to a difference in the contrast between strong and weak syllables. In English, unstressed syllables undergo more vowel reduction. This then increases the saliency of the strong syllables in the language, possibly providing a more salient metrical cue for English-learning infants. The less salient contrast in Dutch might require that infants hear more of the language before they can discriminate between the different levels of stress.

However, as yet only a few behavioral and electrophysiological studies have addressed word segmentation in Dutch (Kooijman et al., 2005, submitted; Kuijpers et al., 1998) and these have all focused on strong–weak words. Here we present the first electrophysiological study of segmentation of weak–strong words in Dutch 10-month-olds, and of the role of the strong syllable in this task. In a familiarization and test paradigm similar to those in HPP studies (Jusczyk & Aslin, 1995), we first familiarized 10-month-old infants with Dutch low-frequency weak–strong words (e.g., *getij* 'tide'), and then tested them on sentences containing the familiarized weak–strong word or a strong–weak word with the same strong syllable as in the familiarized weak–strong words (e.g., *tijger* 'tiger'). In addition, we presented control sentences with unfamiliar weak–strong and strong–weak words. Electroencephalogram (EEG) was measured during both the familiarization and test phases. The design of this experiment allowed us to study brain response to isolated weak–strong words, to the segmentation of weak–strong words from sentence context, and to strong syllables in a different speech context (see Figure 1).

Although we designed an electrophysiological paradigm comparable to the well-known HPP paradigm, some differences have to be pointed out. As in HPP paradigms, we familiarize infants with words in isolation and test them on words in sentences. However, because of the lower signal-to-noise ratio in EEG studies, more familiarization and test combinations have to be presented, so that the average (or event-related brain potential; ERP) over a number of trials can be calculated per condition. The words and sentences presented in the familiarization and test combination vary from trial to trial; per word, the amount of familiarization is comparable to HPP designs. The test phases of the EEG paradigm also differ somewhat from the HPP paradigm. Four different sentences are presented on each trial, two of which contain the familiarized word and two of which include an unfamiliar word. In half of the test phases, these words are weak–strong (e.g., *getij* in *Het wilde getij bedaard* 'The wild *tide* is calming down' or *megeel* in *Hij legt wat megeel in de la* 'He is putting some *megeel* in the drawer'). In the other half, the words are strong–weak (e.g., *tijger* in *De wilde tijger springt* 'The wild *tiger* jumps', or *geler* in *Het is geler dan voorheen* 'It was *more yellow* than before'). Thus, in the results, familiar weak–strong words (*getij*) are compared to unfamiliar weak–strong words (*megeel*), and strong–weak words where the strong syllable is familiar (*tijger*) to unfamiliar strong–weak words (*geler*). Unlike HPP, EEG provides us with the opportunity to test what happens at the moment the infant hears the words in the sentences; it is not an overall measure of the entire sentence. Thus, although there are close similarities between the two methodologies in the input to the infant, the view that the two types of methodology offer of the infant's process-

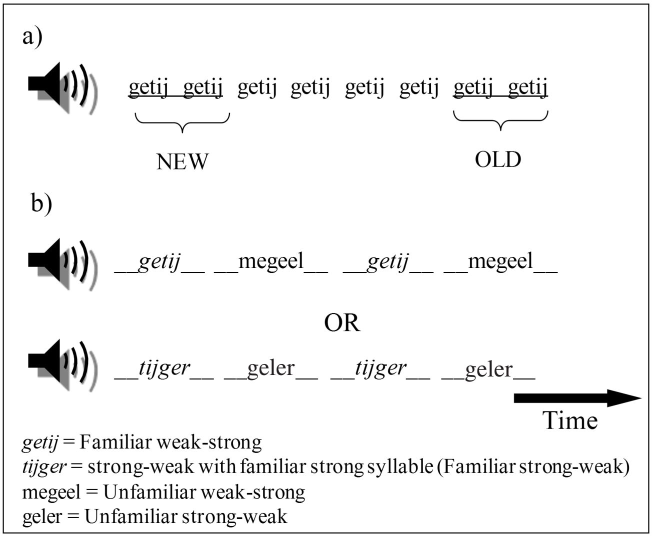


FIGURE 1 Abstract representation of (a) the familiarization phase and (b) the test phase. In the familiarization phase, isolated words are presented. In the test phase, sentences are presented containing the familiarized weak–strong words, strong–weak words with familiar strong syllables and unfamiliar words. The labels are indicated in the picture (old and new in the familiarization phase; familiar and unfamiliar in the test phase). In the familiarization phase, the averaged event-related potentials (ERPs) to the first two tokens (new; underlined) and to the last two tokens (old; underlined) are compared. In the test phase, the averaged ERPs to the familiar weak–strong and unfamiliar weak–strong words are compared, and the averaged ERPs to the strong–weak words with familiar strong syllables (familiar strong–weak) and unfamiliar strong–weak words are compared.

ing is very different. The cross-paradigm differences warrant care in drawing parallels between results from both types of studies.

Considering the ease with which the boundaries of words in isolation can be detected (silence is the clearest marker of a word boundary), we expect an ERP response to the isolated words similar to the response for strong–weak isolated words found by Kooijman et al. (2005). In their study, 10-month-old infants were first familiarized with Dutch low-frequency strong–weak words, and then tested on sentences containing the familiar and unfamiliar strong–weak words. The response to the familiarization phase in their study showed a familiarity effect between 200 and 500 msec. Because the weak–strong words of the familiarization phase in this study are also presented in isolation and therefore have a clear onset, we expect the 10-month-olds to show a similar response in the same time window.

The response to the words in the sentences (test phase), however, is less easy to predict. Dutch infants at 10 months of age are quite proficient at segmentation of strong–weak words (Kooijman et al., 2005; Kuijpers et al., 1998). However, as we noted, Dutch-learning infants seem to be slightly delayed in their segmentation abilities with strong–weak words as compared to English-learning infants (Jusczyk et al., 1999; Kuijpers et al., 1998). Thus, it is not at all certain that Dutch 10-month-olds will be able to make use of multiple segmentation cues in the language to segment weak–strong words from continuous speech. We might find an ERP response time-locked not to the first weak syllable but to the onset of the strong syllable of the weak–strong words (*-tij* in *getij*) only. Assuming such a response to be similar in form to the response found by Kooijman et al. (2005) to strong–weak words in a sentence context after familiarization with words of the same form in isolation, Figure 2 shows the expected ERP pattern if infants rely solely on the strong syllable and take no other segmentation information into account. In Figure 2, the expected pattern is compared to the ERP response found in Kooijman et al. (2005) to familiar and unfamiliar strong–weak words in sentences; it is assumed to start, as in the earlier study, about 350 msec after onset of the strong syllable. If this pattern is found, we would then also expect a similar ERP response to the familiar strong syllables in the strong–weak words in the sentences (*tij-* in *tijger*).

On the other hand, if 10-month-olds are already able to take other segmentation cues into account, we might expect the depicted ERP response to the true onset of the weak–strong words (i.e., the weak syllable; *ge-* in *getij*) and a different ERP

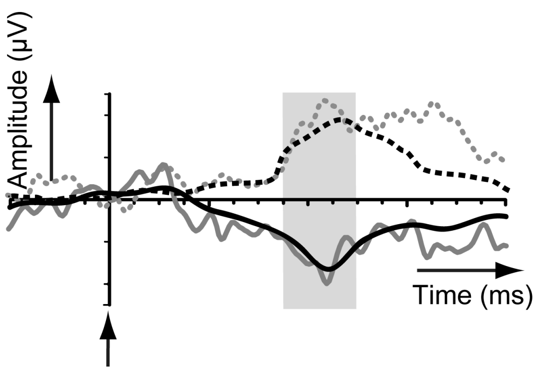


FIGURE 2 Event-related potential (ERP) response to strong–weak words in the test phase of Kooijman et al. (2005; gray lines) and the expected ERP response to the weak–strong words such as *getij* in the test phase of this study (black lines) if the infants only make use of the strong syllable (e.g., *-tij*) for weak–strong word segmentation after familiarization with weak–strong words (dashed line = the ERP to the familiar strong syllables; solid line = the ERP to the unfamiliar strong syllables). The gray area indicates the expected time window of the effect (350–500 msec). The *y*-axis indicates the onset of the strong syllable. Negativity is plotted upward. If the infants use more than just the strong syllable, different ERP results are expected to the weak–strong and strong–weak words in the sentences.

signature to the strong–weak words in the sentences (*tijger*). Differential processing of a repeated weak–strong word as compared to only a repeated strong syllable in sentence context could be indicated by a different ERP response to the strong–weak words than to the weak–strong words in the sentences (thus unlike the response shown in Figure 2). The nature of such differences (in amplitude, latency, polarity, or distribution over the head) cannot be predicted from existing data.

METHODS

Participants

Twenty Dutch 10-month-old infants from monolingual families participated in this study (*M* age = 305 days, range = 283–318 days; 8 girls). Thirty-three additional infants were tested, but excluded from data analyses because, due to restlessness or sleepiness, not enough data were collected. All infants were reported to have normal development and hearing, no major problems during pregnancy and birth, and no neurological or language problems in the immediate family. All infants were born at term. One infant had a left-handed half-brother; the other infants had no left-handedness in the immediate family. The parents signed an informed consent form and received 20 euro for participation.

Stimuli

Thirty-four bisyllabic words with main stress on the second syllable were selected from the CELEX Dutch lexical database (Baayen, Piepenbrock, & Van Rijn, 1993). In addition, because not enough real words could be found that matched to a strong–weak word for pairing purposes, six further bisyllabic pseudowords with the same stress pattern were created (see the Appendix for all 40 word pairs). All words were low in frequency. For each word and pseudoword, a bisyllabic pair with stress on the first syllable was selected or a pseudoword with the same pattern was created. In the two words of a pair, the stressed syllable was the same (e.g., *tij* in the pair *tijger–getij*). For each target word, a set of two sentences was constructed (e.g., *getij* in *Het wilde getij bedaart* ‘The wild *tide* is calming down’ and *tijger* in *De wilde tijger springt* ‘The wild *tiger* is pouncing’). The word preceding the target word and the position of the target word in the sentences were matched across pairs. The target words in the sentences were never in first or final position. A female native Dutch speaker digitally recorded the stimuli in a sound-attenuating booth in a lively child-directed manner.

Design

The experiment consisted of 40 experimental blocks. Each block consisted of a familiarization phase comprising eight tokens of a weak–strong target word, and a test phase consisting of four sentences. In half of the test phases, two sentences contained the familiar weak–strong word the infant had just heard during familiarization, and two contained an unfamiliar weak–strong word. In the other half, two sentences contained the paired strong–weak word (thus, a strong–weak word with the same strong syllable as in the familiarized weak–strong word), and two contained an unfamiliar strong–weak word (see Figure 1). The order of the sentences in each test phase was randomized. Visual and auditory inspection of the speech samples was performed by an experienced researcher using the PRAAT program (Institute of Phonetic Sciences, Amsterdam). The onset of the words and syllables was determined as the earliest point at which it was audible in the sentence. The offset was determined at the latest point at which it was audible. The mean length of the words was 1,080 ms ($SD = 169$ msec) in the familiarization phase (weak syllable: $M = 332$ msec, $SD = 91$ msec; strong syllable: $M = 749$ msec, $SD = 148$ msec). In the test phase the mean length was 748 msec (SD = 126 msec) for the weak–strong words (weak syllable: $M = 247$ msec, $SD = 92$ msec; strong syllable: $M = 501$ msec, $SD = 113$ msec) and 720 msec ($SD = 114$ msec) for the strong–weak words (weak syllable: $M = 267$ msec, $SD = 74$ msec; strong syllable: $M = 453$ msec, $SD = 94$ msec) in the sentences. Words spoken in isolation are naturally longer than words spoken in sentences, hence the difference in word length between the weak–strong words in the familiarization phase and the test phase. This is mostly due to lengthening of the strong syllable in the isolated words. The small difference in length between the target words in the sentences is mostly due to final lengthening of the strong syllable in the weak–strong words. The sentences had a mean duration of 3,190 msec. Four lists were created, counterbalancing test type (i.e., in two of the four lists the weak–strong sentences are replaced by strong–weak sentences and vice versa) and order of presentation (i.e., two of the four lists were presented in reversed order). Each list was presented to 5 infants.

Procedure

The experiment took place in a sound-attenuating test booth. The infant sat in a child seat in front of a computer screen. The parent sat next to the child and listened to a masking CD through closed-ear headphones. The stimuli were presented via loudspeakers placed in front of the infant. Screensavers, not synchronized with the stimuli, were shown to keep the infants interested and still. The child was allowed to play with a small silent toy. The experiment took 24.5 min. We presented as much of the experiment as possible, until the infant got too distracted to continue. Breaks were taken when necessary. All participants heard at least 25 blocks.

EEG recordings and analyses. Infant-size brain caps with 27 Ag/AgCl sintered ring electrodes were used. Twenty-one electrodes were placed according to the American Electroencephalographic Society 10% standard system (midline:

Fz, FCz, Cz, Pz, Oz; frontal: F7, F8, F3, F4; fronto-temporal: FT7, FT8; fronto-central: FC3, FC4; central: C3, C4: centro-parietal: CP3, CP4; parietal: P3, P4; and occipital: P07, P08). Six electrodes were placed bilaterally on nonstandard positions: a temporal pair (LT and RT) at 33% of the interaural distance lateral to Cz, a temporo-parietal pair (LTP and RTP) at 30% of the interaural distance lateral to Cz and 13% of the inion-nasion distance posterior to Cz, and a parietal pair (LP and RP) midway between LTP/RTP and P07/P08. The EEG electrodes were referenced to the left mastoid online and rereferenced to linked mastoids offline. Vertical eye movements and blinks were monitored via a supra- to suborbital bipolar montage (vEOG), and horizontal eye movements via a right-to-left canthal bipolar montage (hEOG). EEG and EOG data were recorded with a BrainAmp DC high-impedance EEG amplifier using a band pass of 0.01 to 200 Hz and a sample rate of 500 Hz. Impedances of the reference and ground electrodes were kept below 5 kΩ; impedances of the EEG and EOG electrodes were kept below 50 kΩ. Seven electrodes were excluded from analysis due to excessive artifact: the midline electrodes Fz, FCz, Cz, and Pz were excluded because of poor fitting of the caps at these electrode positions; the infants' resting of their head on the back of the chair resulted in artifact at electrode positions Oz, P07, and P08. An offline filter of 0.1 to 30 Hz was used. The individual trials were aligned to the onset of the target words and to the onset of the second syllable of the weak–strong target words. Offline, the EEG signal was visually screened for artifact from 200 msec before to 800 msec after the acoustic onset of the target word and second syllable. Trials with amplitudes over 150 μV and trials that showed signals with a clear correlation with the signal on the eye channels (eye artifact and face movement artifact) were rejected. Average waveforms were calculated for each condition for each participant. Time windows for the analyses were chosen based on visual inspection of the grand average waveforms. The averaged ERP to the first two tokens in each familiarization phase (new) was compared to the averaged ERP to the last two tokens in each familiarization phase (old). In the test phase, the ERPs to the repeated weak–strong words (familiar weak–strong) were compared to the unfamiliar weak–strong words (unfamiliar weak–strong); the ERPs to the repeated strong syllables (in the strong–weak words; familiar strong–weak) were compared to the unfamiliar strong–weak words (unfamiliar strong–weak; see Figure 1). In addition, we calculated average waveforms time-locked to the onset of the second syllable of the weak–strong words, because differences in the length of the preceding weak syllables might mask any ERP effects time-locked to the strong, and thus more salient, syllable. The mean number of trials after artifact rejection in each participant average for each condition was 35.5 in the familiarization phase (new: M = 36.5, SD = 9.3, range = 19–53; old: M = 34.3, SD = 11.2, range = 14–56) and 14 in the test phase (familiar weak–strong: M = 13.8, SD = 4.4, range = 9–24; unfamiliar weak–strong: M = 14.6, SD = 4.2, range = 10–24; familiar strong–weak: M = 14.6, SD = 4.1, range = 10–27; unfamiliar strong–weak: M = 15, SD = 3.8, range

= 10–27). There were no significant differences in the number of artifact-free trials per condition within the familarization phase, and within the test phase. Repeated measures analyses of variance (ANOVAs) were performed on the mean amplitudes in the selected time windows with familiarity (familiar vs. unfamiliar), quadrant (4: left frontal, right frontal, left posterior, right posterior), and electrode (5; left frontal: F7, F3, FT7, FC3, C3; right frontal: F8, F4, FT8, FC4, C4; left posterior: LT, LTP, CP3, LP, P3; right posterior: RT, RTP, CP4, RP, P4) as variables. For all tests, the Huynh–Feldt epsilon correction was used. The original degrees of freedom and adjusted *p* values are reported. In addition, effect sizes are reported (partial eta-squared: η^2). For significant effects, additional *t* tests were performed on 50-msec windows with 40-msec overlap (e.g., 0–50 msec, 10–60 msec, etc.) to determine the onset of the effect. Significance on five consecutive 50-msec windows is considered evidence for onset at the beginning of the first 50-msec window.

RESULTS

Familiarization Phase

The ERPs to the old words show a large negative-going deflection as compared to the new words. The grand mean waveforms for the old and new words start to diverge not later than 200 msec after word onset (see Figure 3). Analyses of the 200- to 500-msec time window shows a main effect of familiarity, $F(1, 19) = 15.1$, $p = .001$, $\eta^2 = .44$. The mean amplitude of this effect is 5 µV for representative electrode FC3. Onset tests indicate this effect starts at 140 msec for electrode P4 and at 160 msec for electrodes FC3, FC4, and C4.

The results of the familiarization phase show an effect of repetition similar to the effect found by Kooijman et al. (2005). They tested 10-month-olds on word segmentation of strong–weak words only. Each familiarization phase consisted of 10 tokens of the same bisyllabic strong–weak word. Both the onset and the duration of the effect we found for the weak–strong words are similar to the effect for the strong–weak words in Kooijman et al.'s study. In addition, the effects of both familiarization phases have a mostly frontal distribution, although the effect in this study also seems to be present over a number of posterior electrodes. This might be due to the small differences between the experiments and participant groups (e.g., 8 instead of 10 familiarization tokens).

Test Phase

As explained earlier, the response to the words in the sentences (test phase) is less easy to predict than the response to the words in isolation. However, considering the response to the weak–strong words in isolation (in the familiarization phase),

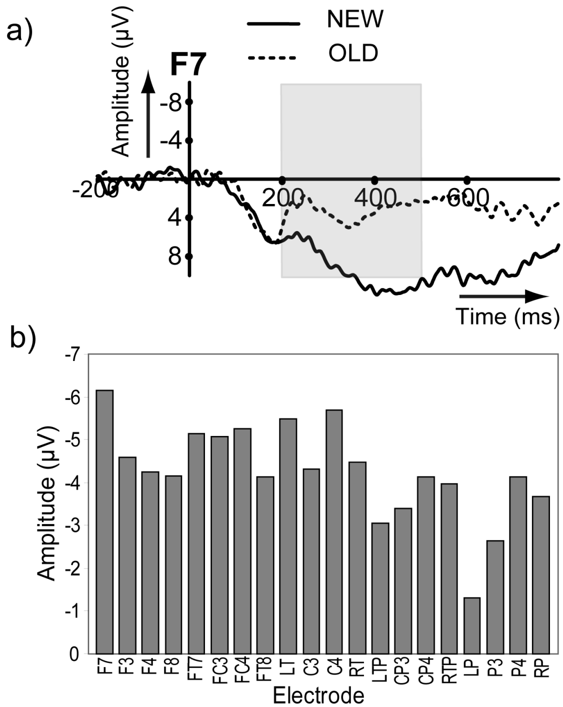


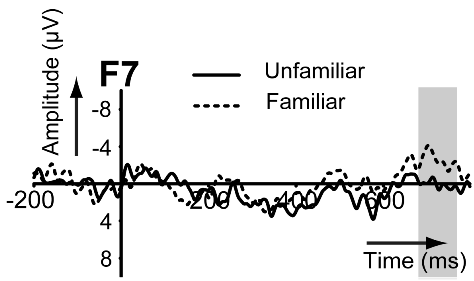
FIGURE 3 Familiarization phase: (a) The grand mean waveforms to the old and new weak–strong words at electrode F7. The gray area indicates the time window selected for analyses (200–500 msec). Negativity is plotted upward. (b) Bar graph of the mean amplitudes of the difference waveform at 20 electrodes. The differences waveform has been calculated by subtracting ERP waveforms to the new isolated words from the old isolated words.

which indicates that the infants built a representation of the entire weak– strong word, we expect to find a negative ERP response (comparable to the response found by Kooijman et al., 2005) to the familiar weak–strong words in the sentences time-locked to the onset of the weak syllable. If this is the case, there might still be a response to the familiar strong syllables in the strong–weak words as well, but with a different signature than the effect evoked by the weak–strong words. Because this is the first (ERP) study on weak–strong word segmentation in Dutch infants, it is difficult to predict the exact nature of this response.

Weak–Strong Words

Inspection of the grand mean waveforms aligned to onset of the words shows a deviation between the familiar weak–strong words and the unfamiliar weak–strong words in the sentences starting at about 600 msec (see Figure 4). Because this deviation is visible at the end of the chosen time window, we also calculated the mean waveforms time-locked to the onset of the second syllable. The ERPs time-locked to the onset of the second, strong, syllable of the words show a larger effect than was seen in the waveforms aligned to word onset. Moreover, the effect is temporally less spread out and has a clearer onset starting at about 370 msec (see Figure 5). This difference between the waveforms is confirmed by statistical analyses. Analyses in the 680- to 780-msec time window after word onset show a marginally significant effect of familiarity, $F(1, 19) = 3.41$, $p = .080$, $\eta^2 = .15$, whereas analyses in the 370- to 500-msec time window from onset of the second syllable show a significant effect of familiarity, $F(1, 19) = 5.00$, $p = .037$, $\eta^2 = .21$. The mean amplitude of this effect is –6.5 μV (for representative electrode FC3). The onset anal-

a)



b)

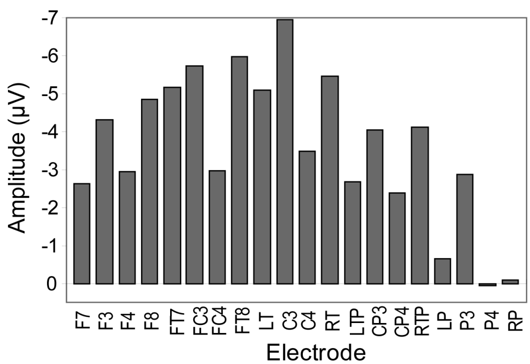


FIGURE 4 Test phase. The grand mean waveform to the familiar weak–strong (WS) and the unfamiliar WS words at electrode F7, aligned to the onset of the target words in the sentences. The gray area indicates the time window selected for analyses (680–780 msec). Negativity is plotted upward; 0 msec is the onset of the target word. (b) Bar graph of the mean amplitudes of the difference waveform at 20 electrodes. The differences waveform has been calculated by subtracting the event-related potential (ERP) waveforms to the unfamiliar WS words from the familiar WS words in the sentences.

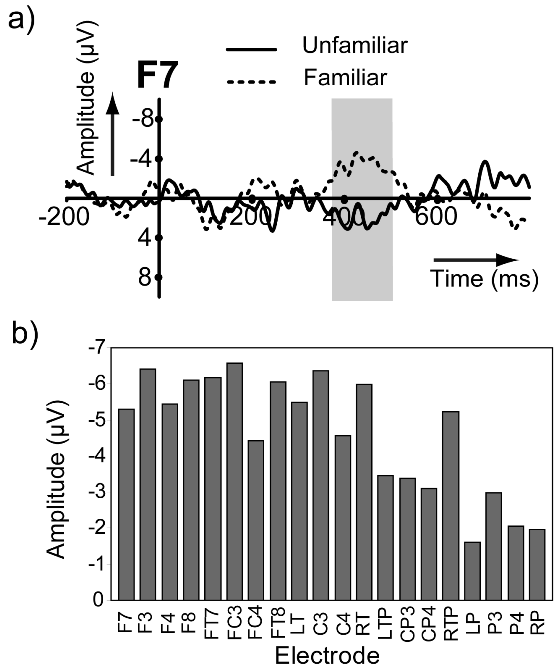


FIGURE 5 Test phase. The grand mean waveforms to the familiar weak–strong (WS) and the unfamiliar WS words at electrode F7, aligned to the onset of the second, strong, syllable of the target words in the sentences. The gray area indicates the time window selected for analyses (370–500 ms). Negativity is plotted upward; 0 msec is the onset of the second syllable of the target words. (b) Bar graph of the mean amplitudes of the difference waveform at 20 electrodes. The differences waveform has been calculated by subtracting the event-related potential (ERP) waveforms to the strong syllables of the unfamiliar WS words from the ERP waveforms to the strong syllables of the familiar WS words.

yses for the strong syllable show that this effect starts at 370 msec for electrodes F3, FT7, FC3, FT8, C3, RT, and RTP.

Strong–Weak Words

The grand mean waveforms of the strong–weak words (aligned to the onset of the word) show a positive-going deflection to the familiar strong syllable of the strong–weak words in the 55- to 135-msec time window as compared to the unfamiliar strong–weak words. This effect is smaller and has a different polarity than the effect to the strong syllable in the weak–strong words. In a later time window, from 300 to 500 msec, the familiar strong–weak words again show a positive-going deflection on several frontal electrodes (see Figure 6).

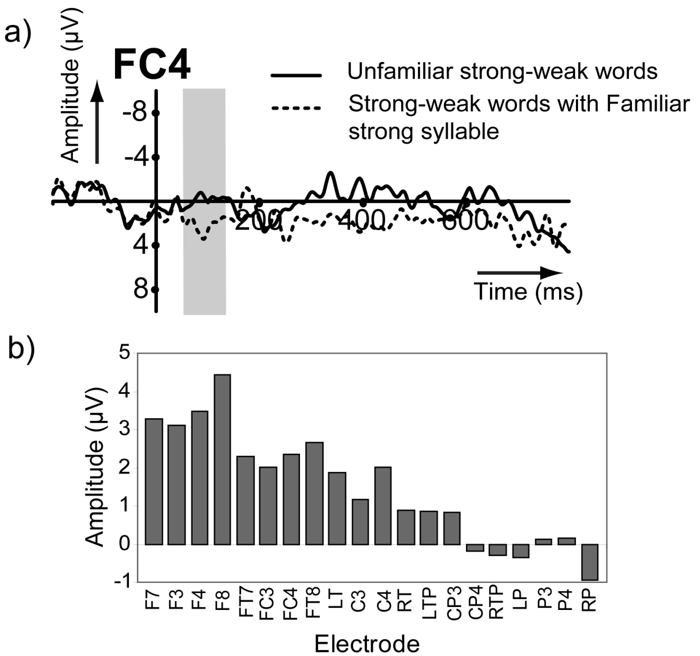


FIGURE 6 Test phase. The grand mean waveforms to the familiar strong–weak (SW) and unfamiliar SW words at electrode FC4, aligned to the strong syllables of the target words in the sentences. The gray area indicates the time window selected for analyses (55–135 msec). Negativity is plotted upward; 0 msec is the onset of the target word. (b) Bar graph of the mean amplitudes of the difference waveform at 20 electrodes. The differences waveform has been calculated by subtracting event-related potential (ERP) waveforms to the unfamiliar SW words from the familiar SW words.

Analyses in the 55- to 135-msec time window revealed a significant Familiarity × Quadrant interaction, $F(1, 19) = 3.07$, $p = .042$, $\eta^2 = .14$. Further analyses per quadrant showed a main effect of familiarity for the right frontal quadrant, $F(1, 19) = 5.56$, $p = .029$, $\eta^2 = .22$. The mean amplitude of this effect is 4.5 µV (for representative electrode F8). Onset tests show a significant onset starting at 40 msec for electrode F8. Note that the effect sizes observed here are comparable to those of an ERP study on word learning in 13- and 20-month-olds (Mills, Plunkett, Prat, & Schafer, 2005).

For the 300- to 500-msec time window a significant Familiarity × Quadrant interaction was found, $F(1, 19) = 3.59$, $p = .023$, $\eta^2 = .16$. Further analyses, however, did not show a main effect of familiarity in any of the quadrants. Additional analyses time-locked to the second syllable on the 200- to 350-msec time window did not reveal any significant effects either, $F(1, 19) < 1$.

GENERAL DISCUSSION

Dutch 10-month-old infants rely principally on strong syllables to find words in continuous speech, even in weak–strong words with which they have been well familiarized. Infants command very little in the way of lexical cues, so that for them, finding word forms in continuous speech amounts to a segmentation operation, and segmentation at strong syllables is the efficient procedure for Dutch. These infants, however, are also sensitive to the context in which strong syllables appear. Overall, the results of this study suggest that Dutch 10-month-olds are beginning to develop a sensitivity to speech cues (or a combination of speech cues) other than the most salient one—syllable stress—with which they first achieved segmentation of words from a continuous speech context. In this first part of the discussion section, we consider this explanation of the data in more detail.

In our experiment, we presented Dutch 10-month-olds with a familiarization phase and a test phase. In each familiarization phase, the infants heard eight tokens of the same bisyllabic weak–strong word. The results for the familiarization phase show a negative-going deflection to the familiar isolated words as compared to the unfamiliar isolated words. This response starts at 160 msec after the onset of the first, weak, syllable, suggesting that Dutch 10-month-old infants process the entire weak–strong word and build a representation over eight presentations of the same word. Fully in line with our prediction, the waveforms are similar in timing and direction to those found by Kooijman et al. (2005) for familiarization with strong–weak words.

Each test phase of the experiment consisted of four sentences, either containing the familiar and an unfamiliar weak–strong word, or strong–weak words with the familiar or an unfamiliar strong syllable. We expected to find a negative ERP response to the familiar weak–strong words in the sentences (comparable to the response found by Kooijman et al., 2005, to strong–weak words in sentences after familiarization; see Figure 2). This response could be either time-locked to the weak syllable or to the strong syllable, depending on the type of information the infants use for weak–strong word segmentation. Considering the results of the familiarization phase, we would expect the effect to be to the weak syllable. However, the results show a familiarity response to the strong syllable of the weak–strong words, from 370 to 500 msec. The mean amplitude of this effect is sizable; that is, –6.5 μV (electrode FC3). This result is similar in polarity and timing to the one found by Kooijman et al. (2005) to the strong syllable of familiar strong–weak words. The finding of a similar response in this study, even after familiarization with a weak–strong word, suggests that infants still primarily rely on the strong syllable for detecting the familiar words in a sentence. This might seem surprising given the brain response to the isolated weak–strong words; in the familiarization phase, as described earlier, a repeated weak–strong word elicited a response entirely comparable to that to a repeated strong–weak word in the predecessor study.

The response even begins well before the end of the first, weak, syllable (onset at 160 msec, *M* syllable length = 332 msec). Thus it is clear that the infants process the repeated isolated weak–strong words from word onset. This certainly suggests that infants form a memory trace of the whole weak–strong word, not just of its strong syllable.

Why, then, do we find that the response in the sentences does not begin immediately on actual word onset? Clearly it is because recognizing a word in isolation is not the same as extracting it from continuous speech. The strongest cue of all to a word boundary, silence, is only reliably present before words presented in isolation. In sentence context, infants can only detect word forms by relying on probabilistic segmentation cues. The strongest probabilistic cue for Dutch is the high likelihood of a strong syllable being word-initial, and this strong cue is inappropriate in this case. Accordingly, recognition beginning from word onset when weak–strong words are presented in isolation cannot automatically entail that recognition will likewise be initiated from the weak syllable when words are presented in sentence context. Our results confirm that the recognition processes in the two situations were indeed different.

The next question then concerns how the recognition response arises in sentences. The test phase results for weak–strong words (*getij*) seem to suggest that infants rely on the strong syllable (*tij*), regardless of the context information. In this case, however, we would expect to see the same ERP response elicited by the familiar strong syllable (*tij*) in the strong–weak words (*tijger*), and this was not what we observed. The response to the onset of this strong syllable was present, but it was much earlier than expected, from 55 to 135 msec, and had an opposite polarity to the response elicited by *tij* in *getij.* The mean amplitude was 4.5 μV (electrode F8). Thus, the test phase ERP responses to the strong–weak and weak–strong words differ considerably. Although we cannot determine from our data which cues in the language are responsible for these differences in timing and polarity, a simple strong syllable explanation, as might have been suggested by the test phase results for the weak–strong words, cannot explain our data.

The following hypotheses might be considered. First, the response to the strong–weak words starts earlier than that to the weak–strong words. This might be partly due to between-word coarticulation cues. Second, the ERP effect time-locked to the onset of the strong syllable of the weak–strong words is larger than the effect to the strong syllable of the strong–weak words, and has an opposite polarity. Moreover, it is distributed over the whole head, whereas the response to the strong–weak words is present only over the right frontal area. These differences could be indicative of partly different processes in the different conditions. Differences in topography and polarity are generally seen as resulting from, at least partly, nonoverlapping underlying neural generator ensembles. This suggests that partly different processes might be at stake (Luck, 2005; Rivera-Gaxiola, Silva-Pereyra, & Kuhl, 2005). Thus it is at least possible that the response to the weak–strong words signals recognition of the familiarized form as a whole whereas the response to the strong syllable in a different (strong–weak) context does not.

In conclusion, we can say that the combined results to the weak–strong and strong–weak words in the sentences suggest that these infants are not simply picking out strong syllables and ignoring the rest of the input; the phonetic context adjacent to a strong syllable also matters to them. The major difference between *tij* in *getij* and *tij* in *tijger* is that the first is preceded by *ge* and the second is followed by *ger.* We suggest that Dutch 10-month-olds are not yet fully in command of the segmentation procedures they need for dealing with weak–strong words, in that they do not show a rapid familiarity response to the initial weak syllable when it is surrounded by other syllables in continuous speech. However, they are sensitive to the difference in immediately adjacent phonetic context, so that although they recognize that *tij* in *tijger* is the strong syllable of what they have been familiarized with, they also recognize that the rest of what they are hearing does not match their stored representation of the whole familiarized form.

There are no ERP findings as yet available for English-acquiring infants hearing weak–strong words. We do not know at what precise point their responses would be initiated. Recall, however, that Jusczyk et al. (1999) argued from their HPP data that 10.5-year-olds were fully in command of the segmentation procedures needed for weak–strong words such as *guitar,* because they resisted false positive responses to *tar* when presented with passages containing *guitar.* Our 10-month-olds are not as selective; their responses to words like *getij* in sentences were clearly dependent on the strong syllable, and were not launched by the initial weak syllable, whereas words such as *tijger* did elicit some response. So just as successful detection of stressed monosyllabic words and of strong–weak words in continuous speech is observed in HPP experiments from 7.5 months in English-learning infants (Jusczyk & Aslin, 1995; Jusczyk et al., 1999), but at 9 months and later in Dutch learners (Kooijman et al., 2005; Kuijpers et al., 1998), so detection of familiar weak–strong forms might occur fully reliably at a slightly later age in Dutch learners. In the remainder of this discussion, we consider an explanation as to why this might be the case.

There is no evidence that Dutch learners are disadvantaged in comparison to English learners in general; for instance, there is no obvious asymmetry in the accessibility of cues to segmental identity in the two languages, and infant sensitivity to mispronunciation of known words seems to be equivalent in English (Vihman, Nakai, dePaolis, & Hallé, 2004) and Dutch (Swingley, 2005). However, the fine detail of language-specific phonological structure exercises considerable influence on the course of development of particular language processing skills. There are, for instance, weaker cues to phrasal juncture in Dutch than in English, and this leads to a comparable lag in infants' use of these cues (Johnson & Seidl, 2008). Similarly, differences in English and Dutch metrical stress patterning fully explain the time course of the effects observed in the word-form familiarization and test experiments in the two populations.

As noted earlier, stress in English and Dutch is highly similar, but not quite similar enough for either adult or infant processing in the two languages to run identical courses. Adult differences are well established (see Cutler, 2005, for a review). In Dutch, as in German and Spanish, the suprasegmental cues to syllable stress (pitch, amplitude, duration) are used in word recognition: Recognition is inhibited by preceding presentation of a fragment with matching segments but mismatching stress (Friedrich, Kotz, Friederici, & Alter, 2004; Soto-Faraco, Sebastián-Gallés, & Cutler, 2001; van Donselaar, Koster, & Cutler, 2005). In English, this inhibition effect is absent (Cooper, Cutler, & Wales, 2002), suggesting that English listeners are not taking suprasegmental stress cues into account. Lexical statistics show that this is a rational strategy, given that in Dutch, competition is significantly reduced when embedded words that mismatch with their carrier words in stress pattern are excluded, whereas in English, the reduction is much smaller (Cutler & Pasveer, 2006). Therefore, English listeners pay little attention to suprasegmental cues to stress, because stress difference usually entails a vowel difference (in *comedy* and *comedian,* not only the stress but also the vowels of *co*- and *me*- differ). Dutch listeners do attend to suprasegmentals, because the same vowels often differ in stress (*komedie,* with second syllable stress, and *komediant,* with final stress, have identical full vowels in both *ko*- and *me*-). Dutch listeners can use the different levels of stress to tell *komedie* from *komediant* just as rapidly as English listeners can use the different vowels to distinguish *comedy* from *comedian.*

The extensive vowel reduction in English effectively amplifies the strong–weak differences, by grouping syllables into two more clearly differentiated categories. In Dutch, there is more gradation, because many syllables have full vowels but are unstressed. In infancy, these cross-linguistic differences could cause rates of development to differ. Although the most effective initial segmentation cue is the same for each language—segmentation at the onsets of strong syllables—it is acted on earlier in the developmental trajectory of young English learners than of young Dutch learners. Although sensitivity to additional cues comes into play in both learner groups by the end of the first year of life, there is effectively more for the Dutch than for the English learners to acquire here, in that discrimination between Dutch syllables requires attention to both segmental and suprasegmental cues, whereas discrimination between English syllables requires attention to segmental structure alone. Dutch adults, as the adult word-recognition literature shows, are sensitive to aspects of speech signals that English listeners usually ignore; the infant literature on recognition of familiarized words in sentences might be tapping into the beginnings of this cross-linguistic asymmetry.

Finally, we note that to fully understand the development of word recognition, we need to know about adult word segmentation as well. So far, there have been only a few studies of adult segmentation using electrophysiological techniques

(Sanders & Neville, 2003; Snijders, Kooijman, Cutler, & Hagoort, 2007). These studies happen to have focused on words with a strong initial syllable (the most common word form in the languages in question, Dutch and English). Thus we do not know yet what the adult ERP response to weak syllables in continuous speech looks like, and whether adults show a response time-locked to the weak syllable at all. This information, preferably from multiple languages, is also necessary to determine at which stage of development infants reach an adult-like level of word segmentation.

ACKNOWLEDGMENTS

This research was supported by the NWO-SPINOZA project "Native and Non-native Listening" (AC). We thank Marlies Wassenaar for recording the stimuli, and all the participants and their parents for taking part in the study.

REFERENCES

Baayen, R. H., Piepenbrock, R., & Van Rijn, H. (1993). *The CELEX lexical database* [CD-ROM]. Philadelphia: Linguistic Data Consortium, University of Pennsylvania.

Bortfeld, H., Morgan, J. L., Golinkoff, R. M., & Rathbun, K. (2005). Mommy and me: Familiar names help launch babies into speech-stream segementation. *Psychological Science, 16,* 298–304.

Cooper, N., Cutler, A., & Wales, R. (2002). Constraints of lexical stress on lexical access in English: Evidence from native and nonnative listeners. *Language and Speech, 45,* 207–228.

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

Cutler, A., & Butterfield, S. (1992). Rhythmic cues to speech segmentation: Evidence from juncture misperception. *Journal of Memory and Language, 31,* 218–236.

Cutler, A., & Carter, D. M. (1987). The predominance of strong initial syllables in the English vocabulary. *Computer Speech and Language, 2,* 133–142.

Cutler, A., & Pasveer, D. (2006). Explaining cross-linguistic differences in effects of lexical stress on spoken-word recognition. In *Proceedings of the Third International Conference on Speech Prosody* (pp. 237–400). Dresden, Germany: TUD Press.

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

Friedrich, C. K., Kotz, S. A., Friederici, A. D., & Alter, K. (2004). Pitch modulates lexical identification in spoken word recognition: ERP and behavioral evidence. *Cognitive Brain Research, 20,* 300–308.

Houston, D. M., Jusczyk, P. W., Kuijpers, C., Coolen, R., & Cutler, A. (2000). Cross-language word segmentation by 9-month-olds. *Psychonomic Bulletin & Review, 7,* 504–509.

Houston, D. M., Santelmann, L. M., & Jusczyk, P. W. (2004). English-learning infants' segmentation of trisyllabic words from fluent speech. *Language and Cognitive Processes, 19,* 97–136.

Johnson, E. K. (2005). English-learning infants' representations of word forms with iambic stress. *Infancy, 7,* 99–109.

Johnson, E. K., & Jusczyk, P. W. (2001). Word segmentation by 8-month-olds: When speech cues count more than statistics. *Journal of Memory and Language, 44,* 548–567.

Johnson, E. K., & Seidl, A. H. (2008). Clause segmentation by 6-month-old infants: A crosslinguistic perspective. *Infancy, 13,* 440–455.

Jusczyk, P. W. (1999). How infants begin to extract words from fluent speech. *Trends in Cognitive Science, 3,* 323–328.

Jusczyk, P. W., & Aslin, R. N. (1995). Infants' detection of the sound patterns of words in fluent speech. *Cognitive Psychology, 29,* 1–23.

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

Jusczyk, P. W., Friederici, A. D., Wessels, J., Svenkerud, V. Y., & Jusczyk, A. M. (1993). Infants' sensitivity to the sound patterns of native language words. *Journal of Memory and Language, 32,* 402–420.

Jusczyk, P. W., Houston, D. M., & Newsome, M. (1999). The beginnings of word segmentation in English-learning infants. *Cognitive Psychology, 39,* 159–207.

Jusczyk, P. W., Luce, P. A., & Charles-Luce, J. (1994). Infants' sensitivity to phonotactic patterns in the native language. *Journal of Memory and Language, 33,* 630–645.

Kooijman, V., Hagoort, P., & Cutler, A. (2005). Electrophysiological evidence for prelinguistic infants' word recognition in continuous speech. *Cognitive Brain Research, 24,* 109–116.

Kooijman, V., Hagoort, P., & Cutler, A. (submitted). Word recognition at seven months: mismatching behavioral and electrophysiological evidence.

Kooijman, V., Johnson, E. K., & Cutler, A. (2008). Reflections on reflections of infant word recognition. In A. D. Friederici & G. Thierry (Eds.), *: Bridging brain and behavior* (pp. 91–114). Amsterdam: John Benjamins.

Kuhl, P. K. (2004). Early language acquisition: Cracking the speech code. *Nature Reviews Neuroscience, 5,* 831–843.

Kuijpers, C., Coolen, R., Houston, D., & Cutler, A. (1998). Using the head-turning technique to explore cross-linguistic performance differences. In C. Rovee-Collier, L. Lipsitt, & H. Hayne (Eds.), *Advances in infancy research* (pp. 205–220). London: Ablex.

Luck, S. J. (2005). *An introduction to the event-related potential technique.* Cambridge, MA: MIT Press.

Mattys, S. L., & Jusczyk, P. W. (2001). Do infants segment words of recurring contiguous patterns? *Journal of Experimental Psychology: Human Perception and Performance, 27,* 644–655.

Mattys, S. L., Jusczyk, P. W., Luce, P. A., & Morgan, J. L. (1999). Phonotactic and prosodic effects on word segmentation in infants. *Cognitive Psychology, 38,* 465–494.

Mattys, S. L., White, L., & Melhorn, J. F. (2005). Integration of multiple speech segmentation cues: A hierarchical framework. *Journal of Experimental Psychology: General, 134,* 477–500.

McQueen, J. M. (1998). Segmentation of continuous speech using phonotactics. *Journal of Memory and Language, 39,* 21–46.

Mills, D. L., Plunkett, K., Prat, C., & Schafer, G. (2005). Watching the infant brain learn words: Effects of vocabulary size and experience. *Cognitive Development, 20,* 19–31.

Morgan, J. L., & Saffran, J. R. (1995). Emerging integration of sequential and suprasegmental information in preverbal speech segmentation. *Child Development, 66,* 911–936.

Myers, J., Jusczyk, P. W., Kemler Nelson, J., Charles-Luce, J., Woodward, A. L., & Hirsch-Pasek, K. (1996). Infants' sensitivity to word boundaries in fluent speech. *Journal of Child Language, 23,* 1–30.

Nazzi, T., Dilley, L. C., Jusczyk, A. M., Shattuck-Hufnagel, S., & Jusczyk, P. W. (2005). English-learning infants' segmentation of verbs from fluent speech. *Language and Speech, 48,* 279–298.

Nazzi, T., Iakimova, G., Bertoncini, J., Frédonie, S., & Alcantara, C. (2006). Early segmentation of fluent speech by infants acquiring French: Emerging evidence for crosslinguistic differences. *Journal of Memory and Language, 54,* 283–299.

Newman, R., Bernstein Ratner, N., Jusczyk, A. M., Jusczyk, P. W., & Dow, K. A. (2006). Infants' early ability to segment the conversational speech signal predicts later language development: A retrospective analysis. *Developmental Psychology, 42,* 643–655.

Norris, D., McQueen, J. M., & Cutler, A. (1995). Competition and segmentation in spoken-word recognition. *Journal of Experimental Psychology: Learning, Memory and Cognition, 21,* 1209–1228.

Rivera-Gaxiola, M., Silva-Pereyra, J., & Kuhl, P. K. (2005). Brain potentials to native and non-native speech contrasts in 7- and 11-month-old American infants. *Developmental Science, 8,* 162–172.

Saffran, J. R., Aslin, R. N., & Newport, E. L. (1996). Statistical learning by 8-month-olds. *Science, 13,* 1926–1928.

Sanders, L. D., & Neville, H. J. (2003). An ERP study of continuous speech processing I: Segmentation, semantics, and syntax in native speakers. *Cognitive Brain Research, 15,* 228–240.

Snijders, T., Kooijman,V., Cutler, A., & Hagoort, P. (2007). Neurophysiological evidence of delayed segmentation in a foreign language. *Brain Research, 1178,* 106–113.

Soto-Faraco, S., Sebastián-Gallés, N., & Cutler, A. (2001). Segmental and suprasegmental mismatch in lexical access. *Journal of Memory and Language, 45,* 412–432.

Swingley, D. (2005). 11-month-olds' knowledge of how familiar words sound. *Developmental Science, 8,* 432–443.

Thiessen, E. D., & Saffran, J. R. (2003). When cues collide: Use of stress and statistical cues to word boundaries by 7- to 9-month-old infants. *Developmental Psychology, 39,* 706–716.

Tincoff, R., & Jusczyk, P. W. (1998). Infants' responses to named and unnamed familiar objects. *Infant Behavior and Development, 21,* 721.

Van de Weijer, J. (1998). *Language input for word discovery: MPI series in psycholinguistics 9.* Nijmegen, The Netherlands: Radboud University.

Van Donselaar, W., Koster, M., & Cutler, A. (2005). Exploring the role of lexical stress in lexical recognition. *Quarterly Journal of Experimental Psychology, 58A,* 251–273.

Vihman, M., Nakai, S., dePaolis, R., & Hallé, P. (2004). The role of accentual pattern in early lexical representation. *Journal of Memory and Language, 50,* 336–353.

Weber, C., Hahne, A., Friedrich, M., & Friederici, A. D. (2004). Discrimination of word stress in early infant perception: Electrophysiological evidence. *Cognitive Brain Research, 18,* 149–161.

APPENDIX
THE 40 TARGET PAIRS OF THE EXPERIMENT

Each pair is shown in weak–strong/strong–weak order. These are 40 pairs of bisyllabic words (or pseudowords). The matching strong syllables of each pair are underlined. Pseudowords are in italics.

getij / tijger; gekruid / kruidig; vertrek / trekker; verwoed / woedend; terecht / rechter; tekort / korter; seleen / lener; sering / ringen; rebel / beller; *ressert* / serre; gebroed / broedsel; geruim / ruimte; verraad / raadsel; verguld / gulden; terras / raster; tegoed / goedig; sedan / danser; sekuur / kuren; regie / gieter; refrein / *freinsel*; *megeel* / geler; beleid / leidster; legaat / gaatje; beloop / loper; meloen / *loenend*; belast / lastig; *penar* / narrig; levant / *vanter*; mekaar / karig; *lemaal* / malen; gelei / leisel; pedaal / daalder; genie / nieter; perron / ronde; legaal / galig; *gevu* / vuren; beschut / schutter; mezelf / zelfde; pedant / *dantel*; genant / *nantig*