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PAPER

Rapid recognition at 10 months as a predictor of language development

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Abstract

Infants' ability to recognize words in continuous speech is vital for building a vocabulary. We here examined the amount and type of exposure needed for 10-month-olds to recognize words. Infants first heard a word, either embedded within an utterance or in isolation, then recognition was assessed by comparing event-related potentials to this word versus a word that they had not heard directly before. Although all 10-month-olds showed recognition responses to words first heard in isolation, not all infants showed such responses to words they had first heard within an utterance. Those that did succeed in the latter, harder, task, however, understood more words and utterances when re-tested at 12 months, and understood more words and produced more words at 24 months, compared with those who had shown no such recognition response at 10 months. The ability to rapidly recognize the words in continuous utterances is clearly linked to future language development.

Introduction

The ability to recognize a previously heard word form is vital for developing a vocabulary. Vocabulary construction requires identifying both concepts and spoken forms, and mapping between them (Waxman & Lidz, 2002). One of the best-documented early lexical phenomena is toddlers' rapid vocabulary explosion once they have laboriously acquired their first words. At this stage learners are capable of 'fast mapping' (Carey & Bartlett, 1978): acquiring the meaning of a novel word after only a single brief or incidental exposure. All of the elements of vocabulary construction must be in place for that kind of learning to be possible: the ability to identify concepts, the ability to map a concept to a spoken form, and the ability to create a memory representation of a spoken form. These are assumed to be separate skills; a memory representation, for instance, can be created without a corresponding concept being available.

The present study investigates whether infants at 10 months of age can create such a word-form memory after hearing a form for the first time. Further, we investigate the kinds of auditory experience that can support this achievement. The words that infants hear occur mainly in continuous speech, with no reliable pauses marking word boundaries in the speech signal (Morgan, 1996; Van de Weijer, 1998; Woodward & Aslin, 1990). Identifying (boundaries between) words in continuous speech is hence a crucial ability for vocabulary acquisition. Indeed, infants' performance in speech segmentation tasks is directly related to later language development (Junge, Hagoort, Kooijman & Cutler, 2010; Newman, Bernstein Ratner, Jusczyk, Jusczyk & Dow, 2006). Therefore we assess the recognition of forms heard both in isolation and in running speech.

Not much is known about how many times a word form should be presented before an infant starts recognizing it. One corpus study (van de Weijer, 1998) suggested that an infant aged between 6 and 9 months hears, all told, about two and a half hours of speech a day; however, 86% of this heard speech in the Van de Weijer corpus was directed to adults or others in the environment, and only 14% of it actually to the infant listener. The infant-directed speech, predominantly made up of multi-word utterances, had a significantly lower type–token ratio than the speech of the same adults to the child's older sibling. The parents used only about half as many different words to address to the infant as they used with their older child. In other words, parents tend to repeat words when they are talking to infants, which should certainly help with the build-up of a vocabulary. These statistics do not demonstrate, however, the limits of infants' abilities to store and recognize word forms.

Speech segmentation studies, directly assessing whether and how well infants recognize words in continuous

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speech, can provide such information. Most of the cues that infants can use to detect word boundaries must, of necessity, be learned through native language experience (Cutler, 2002). The cues are generally probabilistic rather than fully reliable, and no single cue is sufficient to detect all word boundaries (Kuhl, 2004). Thus the ability to segment speech efficiently develops gradually with increasing listening experience. Jusczyk and Aslin (1995) first studied infants' ability to segment speech, creating a two-stage familiarization-and-test version of the behavioral Headturn Preference Procedure (HPP; Fernald, 1985). They presented infants first with lists of 15 tokens of each of two words, spoken in isolation. In the test phase, infants listened longer to short texts containing these words compared to other texts containing similar words that had not been presented in the familiarization phase. Thus they recognized the words that they had first heard in isolation when they recurred in the continuous speech in the texts. Jusczyk and Aslin demonstrated that the reverse is true, too: At test, infants can recognize isolated presentations of words that were heard during the familiarization phase in continuous speech. The number of times infants heard each target word during familiarization in this case was at least 12.

Subsequent research focused on various, sometimes conflicting, segmentation cues in the speech signal. Jusczyk, Houston and Newsome (1999) showed that American-English 7.5-month-olds can use stress as a word-onset cue; in Germanic languages, initial word stress is the dominant pattern (English: Cutler & Carter, 1987; Dutch: Schreuder & Baayen, 1994). Other cues that infants use include language-specific phonetic and phonotactic regularities (e.g. Mattys, Jusczyk, Luce & Morgan, 1999) or statistical transitional probabilities between syllables (e.g. Saffran, Aslin & Newport, 1996). Clearly, HPP has brought great insights into the processes whereby infants detect words in speech. In all cases infants were familiarized multiple times with words before preference for familiar versus unfamiliar words was tested.

Event-related potentials (ERPs) provide another measure of infants' ability to recognize words in speech. While HPP demonstrates the occurrence of word segmentation, it cannot reflect its time course; speech segmentation ability is reflected in HPP by difference in mean headturn times to passages containing occurrences of familiarized words versus passages containing occurrences of unfamiliar words. An on-line segmentation measure, in contrast, provides a window onto the moment in time when infants recognize a word in continuous speech. Kooijman, Hagoort and Cutler (2005) developed an electrophysiological analog of the familiarization-and-test HPP paradigm. They familiarized 10-month-olds with infrequent words by presenting these 10 times in isolation; they then recorded ERPs to these familiarized words, and to matched unfamiliarized words, in continuously spoken texts. Due to the lower signal-to-noise ratio characteristic of ERP experiments, their study involved more familiarization and test combinations than is typical of HPP studies (i.e. in their ERP experiment, infants were familiarized with a maximum of up to 20 different words, whereas in HPP studies infants are generally familiarized with two different words). Infants showed a negativity over left frontal electrodes around 400 ms from onset of the familiarized words relative to the onset of unfamiliarized words. This negativity appears to be a quite stable recognition response for this age group: it has appeared in other word segmentation studies in our laboratory with 10-month-olds (Junge, Cutler & Hagoort, submitted; Kooijman, Hagoort & Cutler, 2009), as well as in French 12-month-olds (Goyet, de Schonen & Nazzi, 2010) and in German 12-month-olds (Männel & Friederici, 2010). The timing of the effect indicates that infants initiate a recognition response before the word has ended.

Both behavioral and electrophysiological studies on speech segmentation ability have thus shown that a familiarization phase of around 10 isolated tokens suffices for infants below the age of 1 to subsequently distinguish between the familiarized word in question and a similar but unfamiliarized word, both presented in continuous speech. But how often should infants hear a word before they can classify this word as familiar? The on-line measure of ERPs allows us to address this question too. In the present study we assess whether we can detect recognition based on a memory trace of a word heard a single time. We compare whether this word is first heard in a continuous utterance, or in isolation. We refer to familiarization with a token in continuous speech as the segmentation condition. After familiarization, infants hear a test word in isolation, either one that was part of the utterance, or an unfamiliar word. Recognition of the familiar item indicates that infants have not only segmented the prior utterance into its component words, but also remembered the results. To ensure that the requisite memory abilities are present, we also have a condition in which the familiarization phase consisted of a single isolated token (the memory condition), with the same test phase as the segmentation condition. Familiarity effects in the (easier) memory condition would rule out the possibility of a null effect in the segmentation condition being due to memory insufficiency.

Based on our previous findings (Kooijman *et al*., 2005, 2009), we predict that ERPs will be more negative for familiarized words than for unfamiliarized words, regardless of the type of familiarization prior to the test phase. For the segmentation condition we predict a left frontal negativity similar to the negativity in the test phase in Kooijman *et al*. (2005). For the memory condition, we also expect a negative ERP response of familiarity, based on responses for isolated words in the familiarization phase of Kooijman *et al*. (2005, 2009).

As noted above, infant segmentation skill is related to later language development; here we therefore further examine the relationship between our 10-month-olds' results and their language skills at 12 and 24 months. Newman *et al*. (2006) compared performance on a variety of tasks in the first year and expressive vocabulary size at two years, focusing on the infants who scored at the top and bottom 15% of the sample at the latter age. The difference between children with large and small expressive lexicons at 2 years was clearly apparent in early performance on speech segmentation tasks (but not on tasks measuring language discrimination or prosodic preferences): Children with large lexicons showed better speech segmentation skill. Junge *et al*. (2010) compared children's language quotients at 3 years and their performance at 7 months in an ERP speech segmentation task with the same design as Kooijman *et al*. (2005). Although most 7-month-olds had shown the negative ERP familiarity effect for words repeated in isolation across the familiarization phase, the majority showed a reverse-polarity effect when these words were then heard in sentences. Yet there were differences within the group, with some of the infants also showing, at test, the negative familiarity effect as reported by Kooijman *et al*. Those 7-month-olds who showed the 10-month-old pattern then proved to have higher language quotients at 3 years than their age-mates. Indeed, the size of the negativity over left frontal electrodes in infancy was positively correlated with later vocabulary quotients. However, the measure of the ERP familiarity effect for the familiarization phase (isolated words) did not correlate with later language measures. We therefore predict a similar gradient effect in the present study for subsequent language measures with the ERP correlate of word recognition from continuous speech, but not with that of word recognition in isolation. Specifically, we hypothesize that infants with better segmentation skill, in the form of a larger negative ERP effect of familiarity, will outscore their peers on subsequent language tests.

Methods

Participants

Data from 28 monolingual Dutch 10-month-olds (mean age = 307 days, range 293–318 days; 13 girls) were retained for analysis. An additional 17 infants were excluded from further analysis because of too few artifact-free trials ($n = 8$); fussing or crying ($n = 4$); refusal to wear the cap ($n = 3$), or missing follow-up information ($n = 2$). All infants were reported to have normal development and hearing, with right-handed parents, and no history of language or neurological impairments in the immediate family. Infants were recruited from the Nijmegen Baby Research Center Database; most had middle-class, college-educated parents. Parents signed an informed consent form, and received 20 euro and a photograph taken after the experiment in appreciation of their participation.

Materials and procedure

The experiment comprised 160 trials: 80 sentence–word trials for the segmentation condition, and 80 word–word trials for the memory condition, with 40 trials for each condition having a familiarized word in the test phase, and 40 having an unfamiliarized word. The two conditions were pseudo-randomly presented throughout the experiment, with the restrictions that any two trials with a given test word were separated by at least 10 intervening trials, and there were no more than five types of any one condition in a row.

We selected 40 pairs of unrelated Dutch bisyllables with trochaic stress (e.g. *hommel* 'bumblebee', *mammoet* 'mammoth'). All words and their component syllables were low in frequency (CELEX Dutch lexical database; Baayen, Piepenbrock & van Rijn, 1993), and were not present in the Dutch version of the CDI. For each word, we chose from previous studies (Kooijman *et al*., 2005, 2009) two sentences containing this word in non-initial and in non-final position.

For the memory trials, the familiarization token was excised from the sentences, thus keeping acoustic properties of the target words in the familiarization phases constant across conditions. Hence, infants first hear a single word (memory condition) or a single sentence (segmentation condition) during the familiarization phase, and then hear in the test phase a novel token of a word in isolation that either also occurred in the preceding familiarization phase ('familiar') or not ('unfamiliar'). Table 1 presents an example of the word pair *hommel*-*mammoet* over the four conditions of our 2×2 within-subjects design. Half of the participants (group A: 14 infants) were familiarized in the memory condition with the word *mammoet*, extracted from one of the two utterances in the table, and in the segmentation condition with the other word, *hommel*, embedded in one of the two utterances shown. The other 14 infants (group B) heard *hommel* in the memory condition and *mammoet* in the segmentation condition. For each condition, infants received familiarization with the same word twice, once followed in the test phase by the same word ('familiar') and once followed by a word that was not part of the previous familiarization phase ('unfamiliar'); these two familiarizations always involved different utterances so that the same acoustic token was never heard twice. The two familiarization tokens were also counterbalanced within each group (giving four lists in total, each presented to seven infants). In addition, each list had a balanced order of which trials per word pair were presented first (familiar versus unfamiliar; segmentation versus memory condition).

In the test phase, a given item could then serve as familiarized in one condition and as unfamiliarized in the other. This entailed, of course, that infants could receive in one condition an 'unfamiliarized' word that they had actually heard before as a familiarized item in the other condition. When this was the case, there were

Table 1 *An example of an experimental pair (e.g. 'hommel'-'mammoet') for the familiar and unfamiliar conditions for the memory and segmentation trials, respectively. Familiarization and Target words are in bold, with the English equivalent in parentheses. Infants from group A are familiarized with 'mammoet' for the memory trials, and with 'hommel' for the segmentation trials. This pattern is reversed for infants from group B. Note that the word for the familiarization phase of the memory condition in one group is spliced from the utterance in the familiarization phase of the segmentation condition from the other group*

	Familiar		Unfamiliar	
Condition	Familiarization phase	Test phase	Familiarization phase	*Test phase*
Group A Memory	**mammoet$_i$** (mammoth)	**mammoet$_j$**(mammoth)	**mammoet** (mammoth)	**hommel** (bumblebee)
Segmentation	Een kleine **hommel$_i$** zit op het gordijn (A small bumblebee sits on the curtains)	**hommel$_j$**(bumblebee)	Het is een oude **hommel** met gele strepen (It is an old bumblebee with yellow stripes)	**mammoet** (mammoth)
Group B Memory	**hommel$_i$**(bumblebee)	**hommel$_j$** (bumblebee)	**hommel** (bumblebee)	**mammoet**(mammoth)
Segmentation	Die kleine **mammoet$_i$** zwemt in de rivier (That small mammoth is swimming in the river)	**mammoet$_j$** (mammoth)	Er is een oude **mammoet** in het museum(There is an old mammoth in the museum)	**hommel**(bumblebee)

on average 39.4 (*SD* 15.7) intervening familiarization-and-test trials, which corresponds to an average of 244.1 seconds (*SD* 98.8) between the trial in which a word was familiarized for one condition and the trial in which the same word was considered to be unfamiliar for the other condition. A recent study (Goyet *et al.*, 2010) demonstrated that the recognition effect in infants is quite localized in time (but see Jusczyk & Hohne, 1997; Houston & Jusczyk, 2003). Goyet and colleagues succeeded in finding a word recognition effect (familiarized versus unfamiliarized) in an experiment involving only four words, each presented in up to five separate familiarization phases, each of 10 isolated tokens. Note that any consequent attenuation of the familiar/unfamiliar difference would in any case only reduce our chance of finding a significant effect.

The 160 sentences (40 pairs × two words × two sentences per word) were digitally recorded in a sound-attenuating booth by a female native speaker of Dutch, speaking in a lively child-directed manner. They were sampled to disk at 16 kHz mono. The 80 test words, uttered in isolation, were also recorded. As words spoken in citation form are in general longer than the same words spoken in utterances, this means that the target words in our test phase were longer than the corresponding words in the familiarization phases. Mean sentence duration was 3463 ms (*SD* = 615); mean target word duration was 937 ms (*SD* = 265 ms) in isolation, and 714 ms (*SD* = 134) in sentences.

During test, infants were awake and seated in a child seat, facing a computer screen in a sound-attenuating booth. The infant could watch screen savers (not synchronized with the auditory input) on a computer screen, or play with a silent toy. A parent sat by the child, listening to a masking CD through closed-ear headphones. Breaks were taken when necessary. Two loudspeakers presented the auditory stimuli. In segmentation trials a 300 ms interval separated sentence offset and target word, with a 1500 ms interval before the next familiarization-and-test trial started. In memory trials, the inter-trial intervals (between the target word offset from the previous trial and the current prime word onset) and the intra-trial intervals (between the prime word offset and target word onset) were matched to that in the corresponding segmentation trials (mean of inter-trial intervals = 2517 ms, *SD* = 687, range 1587–4181; mean of intra-trial intervals = 1956 ms, *SD* = 746, range 771–4184). ERPs were collected and time-locked to the onset of target words. The experiment lasted about 15 minutes.

EEG recordings and analyses

We recorded EEGs with infant-size Brain-Caps (cf. Kooijman *et al.*, 2005, 2009), with 21 regularly spaced Ag/AgCl electrodes. Fourteen electrodes were placed according to the 10/20 International system (F3, F4, F7, F8, FT7, FT8, FC3, FC4, C3, C4, CP3, CP4, P3, and P4). The remaining six electrodes were placed bilaterally on non-standard positions: a temporal pair (LT and RT) at 33% of the interaural distance lateral to CZ; a temporal-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 PO7/PO8. The electrooculogram was recorded from three electrodes placed over and one under the eye to monitor blinks and eye movements. Electrodes were referenced to the left mastoid online and rereferenced to linked mastoids offline. Impedances were kept below 5 kΩ for the ground and reference electrodes, and below 20 kΩ for the remaining electrodes. The EEG was sampled at 500 Hz. The signal was filtered on-line (0.01–200 Hz), with an off-line filter of 0.1–30 Hz. Individual trials with a baseline of 200 ms were screened for artifact from 200 ms before to 800 ms after target word onset. Trials were automatically rejected when amplitudes exceeded ± 150 μV, and manually rejected when we detected drift or artifacts as indicated by clear correlations on the eye channels or the active right mastoid. The person performing the visual inspection of artifacts was blind to later language development of the infants. For each infant, we calculated average waveforms per condition, with a minimum criterion of 10 artifact-free trials per condition. Infants had on average 16.5 (range 10.3–25) artifact-free trials per condition (maximum 40).

For both the memory and the segmentation conditions, we compared ERPs time-locked to target words for familiar and unfamiliarized words. This was done separately for each Familiarization Type (memory, segmentation), because the timing of the familiarity effect could differ per condition. Therefore, time windows were selected based on visual inspection of the waveforms. Repeated measures analyses of variance (ANOVA) were performed on the mean amplitudes in selected time windows, with Familiarity (familiar vs. unfamiliar), Quadrant (four: left frontal, right frontal, left posterior, right posterior), and electrode (five; 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 within-subject variables. To measure the interaction of later vocabulary with ERP effects, we calculated vocabulary group membership as a between-subjects variable, based on a median split of vocabulary size at 12 months. For all ANOVA tests, we used the Huynh-Feldt epsilon correction and report original degrees of freedom, adjusted p-values, and adjusted effect sizes (partial eta-squared: η^2).

Measuring later language development

We assessed each infant's language skills at 12 and 24 months, using a Dutch version of the MacArthur-Bates Communicative Development Inventory (CDI: Fenson, Dale, Reznick, Bates, Hartung, Pethick & Reilly, 1993; N-CDI: Zink & Lejaegere, 2002). For 12-month-olds we used the Infant-CDI, which tests comprehension and production of 31 typical utterances and 434 words in 19 semantic categories, and for 24-month-olds we used the Toddler-CDI, for ages 16 to 30 months, also measuring vocabulary comprehension and production (702 words in 22 semantic categories).

Results

At 10 months: the memory condition

Figure 1a shows the mean waveforms for words that were versus were not presented in familiarization in isolation. It can be seen that both familiar and unfamiliar words elicit a large positive wave starting from 100 ms, which is typical for isolated auditory word processing (e.g. Kooijman *et al.*, 2005; Friedrich & Friederici, 2005). As predicted, this positivity of ERPs is clearly reduced for familiarized words compared to unfamiliarized words. Based on visual analysis we selected the time window 200–650 ms from word onset. There was a main effect of Familiarity ($F(1, 27) = 4.72$, $p = .039$, $\eta^2 = .15$), with a similar latency and anterior distribution as observed in the familiarization phases with isolated words in previous studies (Kooijman *et al.*, 2005, 2009). The polarity of the effect was also what we predicted based on these previous studies: Compared to the large positive ERPs for unfamiliar words, the ERPs for familiarized words are more negative (or less positive). Observing the hypothesized negative Familiarity effect around 400 ms suggests that 10-month-olds indeed recognize words after a single isolated exposure, and thus command a prerequisite for recognizing words previously presented within an utterance.

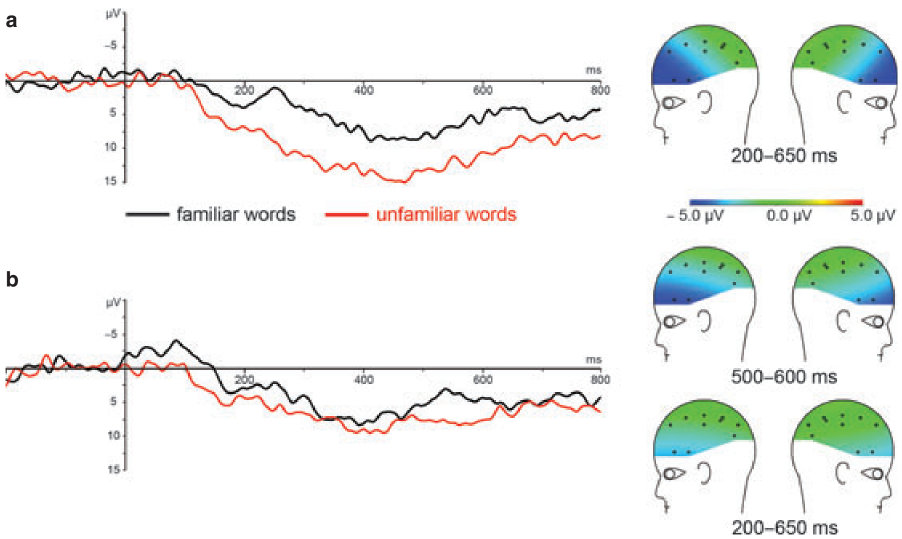

Figure 1 *Grand average waveforms for the familiarized and unfamiliarized words at left frontal electrode F7 on the left; negativity is plotted upwards; 0 ms indicates word onset. On the right, isovoltage plots of the familiarity effect (familiarized – unfamiliarized words), corresponding with the selected time windows. 1a. Results of the memory condition. 1b. Results of the segmentation condition.*

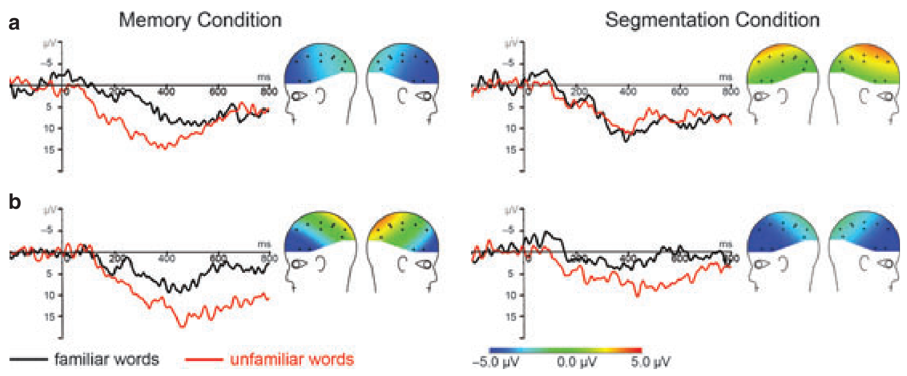

Figure 2 *Grand average waveforms, split by Vocabulary Group and Familiarity Type for the familiarized and unfamiliarized words at left frontal electrode F7; negativity is plotted upwards; 0 ms indicates word onset, with the corresponding isovoltage plots of the familiarity effect (familiarized – unfamiliarized words) for the time window 200–650 ms. 2a. Results for the infants in the Lower Vocabulary Size (LV) Group. 2b. Results for the infants in the Higher Vocabulary Size (HV) Group. Although both groups show a familiarity effect in the memory condition, only HV infants show a familiarity effect in the segmentation condition.*

At 10 months: the segmentation condition

Figure 1b shows the grand average waveforms for familiarized and unfamiliarized words in the segmentation condition, where the familiarization had involved continuous utterances. Visual inspection shows a small time window (500–600 ms) where the waveforms slightly diverge, with that of the familiarized word being, as predicted, more negative. There was, however, no significant main effect of Familiarity ($F(1, 27) = 1.84$, $p = .19$, $\eta^2 = .06$), nor did the Familiarity effect reach significance ($p < .05$) in any individual quadrant (left frontal: ($F(1, 27) = 3.13$, $p = .088$, $\eta^2 = .10$; right frontal: $F(1, 27) = 0.65$, $p = .43$, $\eta^2 = .02$; left posterior: $F(1, 27) = 1.15$, $p = .29$, $\eta^2 = .04$; right posterior: $F(1, 27) = 0.94$, $p = .34$, $\eta^2 = .03$). We also examined the time window 200–650 ms, the same time window as for the memory condition. Although 18 of the 28 infants displayed an effect of Familiarity, with similar polarity and left frontal distribution as we had predicted from previous studies (Kooijman *et al*., 2005, 2009), there was no significant overall effect of Familiarity ($F(1, 27) = 0.64$, $p = .43$, $\eta^2 = .02$). The lack of a main effect of Familiarity suggests that the 10-month-olds in our study cannot yet recognize words previously heard only within utterances.

Recognizing words at 10 months and language development at 12 months

To compare speech segmentation ability and vocabulary at 12 months, we created two subgroups by a median split of vocabulary size. Infants in the lower vocabulary size group (LV) comprehended on average 40 words and utterances (range 2–68; six girls), and infants in the higher vocabulary size group (HV) understood on average 146 words and utterances (range 71–264; seven girls). The two groups did not differ significantly in male/female ratio or in the number of artifact-free trials per condition ($p > .4$).

To compare the two groups on their ERP responses across familiarization conditions at 10 months, we entered mean amplitude values in the 200–650 ms latency range into an omnibus ANOVA, with Familiarity, Familiarization Type and Quadrant as within-subjects factors, and Vocabulary Group (LV, HV) as between-subjects factor. There was no main effect of Familiarity ($F(1, 26) = 3.49$, $p = .073$, $\eta^2 = .12$) and no significant interactions of Familiarity with Familiarization Type ($F(1, 26) = 0.43$, $p = .52$, $\eta^2 = .02$) or with Vocabulary Group ($F(1, 26) = 0.46$, $p = .50$, $\eta^2 = .02$). However, a significant three-way interaction of Familiarity by Familiarization Type by Vocabulary Group[1] ($F(1, 26) = 8.09$, $p = .009$, $\eta^2 = .24$) appeared; Depending on the familiarization phase, infants with lower versus higher vocabulary sizes differ in their Familiarity effect.

We accordingly examined the ERP results for LV and HV infants separately. Figure 2 shows the topographical distribution for the Vocabulary Groups for both types of Familiarization. For the LV group, there was no main effect of Familiarity across conditions ($F(1, 13) = 0.54$, $p = .48$, $\eta^2 = .04$), but there was a significant interaction of Familiarity and Familiarization Type ($F(1, 13) = 7.12$, $p = .019$, $\eta^2 = .35$). Infants with lower vocabulary sizes showed a significant effect of Familiarity only in the (easier) memory condition ($F(1, 13) = 6.69$, $p = .020$, $\eta^2 = .35$), not in the (harder) segmentation condition ($F(1, 13) = 0.66$, $p = .43$, $\eta^2 = .05$).

[1] The pattern of results also holds when we calculated the between-groups measure 'Vocabulary group' based on their vocabulary size at 24 months instead of 12 months, even though four children from each group move to the other group. The three-way interaction of Familiarity by Familiarization Type by Vocabulary Group is still significant ($F(1, 26) = 5.76$, $p = .024$, $\eta^2 = .18$), with similarly non-significant main effects of Familiarity or interactions of Familiarity with Familiarization phase or Vocabulary Group ($p > .06$). More importantly, at an individual level, there is still a relationship between the ERP correlate of speech segmentation ability and vocabulary size at 24 months.

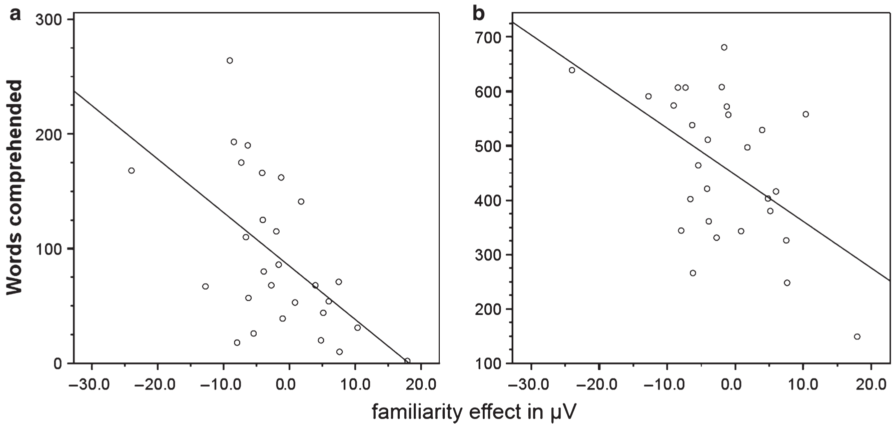

Figure 3 *Relation between segmentation ability at 10 months, as measured by the individual amplitude difference (familiarized – unfamiliarized words) over left frontal electrodes in the time window 200–650 ms (segmentation condition), and the number of words understood at 12 (3a) or at 24 months (3b), respectively.*

For infants with higher vocabulary sizes, however, the main effect of Familiarity was significant ($F(1, 13) = 4.79$, $p = .047$, $\eta^2 = .27$), regardless of Familiarization Type ($F(1, 13) = 2.10$, $p = .17$, $\eta^2 = .14$). There was further a significant interaction of Familiarity by Quadrants ($F(1, 13) = 4.30$, $p = .013$, $\eta^2 = .25$): across Familiarization Types, the Familiarity effect was only significant on left frontal electrodes ($F(1, 13) = 15.41$, $p = .002$, $\eta^2 = .54$).

Although it is in the left frontal quadrant that the effect for infants in the HV group in both conditions is most visible, visual inspection of Figure 2 shows that the effect in the segmentation condition is more broadly distributed than in the memory condition. Statistical analyses confirm this: There is a main effect of Familiarity in the segmentation condition ($F(1, 13) = 4.94$, $p = .045$, $\eta^2 = .28$; interaction of Familiarity × Quadrant $F(3, 39) = 0.81$, $p = .48$, $\eta^2 = .06$)), but a local effect in the memory condition that is significant only for the left frontal quadrant ($F(1, 13) = 8.50$, $p = .012$, $\eta^2 = .40$). Yet even with a broadly distributed effect for the segmentation condition, it is only on left frontal electrodes that the Familiarity effect is most prominent ($F(1, 13) = 7.01$, $p = .020$, $\eta^2 = .35$).

Visual inspection of Figure 2 further shows that both time course and distribution of the Familiarity effect in the memory condition differ across groups. For LV infants, the Familiarity effect starts earlier, at 200 ms, but also ends earlier, around 500 ms. For this time window, LV infants show a broadly distributed Familiarity effect ($F(1, 13) = 18.78$, $p = .001$, $\eta^2 = .59$), whereas HV infants only show a significant effect on the four left frontal electrodes F3, FT7, F7 and FC3 ($F(1, 13) = 5.17$, $p = .041$, $\eta^2 = .29$). For the later time window 500–650 ms, this effect is no longer significant for infants in the LV group ($F(1, 13) = 0.39$, $p = .54$, $\eta^2 = .03$), but their HV peers still show a Familiarity effect in the left frontal quadrant ($F(1, 13) = 12.09$, $p = .004$, $\eta^2 = .48$).

To summarize, although both Vocabulary Groups show a Familiarity effect for words heard once in isolation (memory condition), only HV infants, with better language development, show this effect for words heard once within an utterance (segmentation condition). The latter situation required 10-month-olds to segment sentences on first hearing in the familiarization phase to enable recognition of the segmented word at test.

In further comparisons with subsequent language development we therefore used the average difference between ERPs for familiarized and unfamiliarized words on left frontal electrodes in the time window 200–650 ms as an index of speech segmentation ability at 10 months. Figure 3a shows a significant relationship between this difference and comprehension vocabulary size at 12 months ($r = -0.56$, $r^2 = 0.32$, $p = 0.002$): The larger the difference, the more words and phrases the infant understood at 12 months.[2] When we calculate an equivalent index of memory ability in terms of the average difference between ERPs for familiarized and unfamiliarized words on left frontal electrodes in the tested time window, we see no such pattern ($r = +0.076$, $r^2 = 0.006$, $p = .70$). The memory and segmentation indices themselves are also not related ($r = -0.036$, $r^2 = 0.001$, $p = .86$). This suggests that speech segmentation ability is related to language development at 12 months but memory ability is not.

[2] The pattern of results holds when we exclude the outlier with an index of speech segmentation ability of -24 µV from analyses. We still observe a significant three-way interaction of Familiarity by Familiarization Type by Vocabulary Group ($F(1, 26) = 6.58$, $p = .017$, $\eta^2 = .21$), without a main effect of Familiarity ($F(1, 26) = 2.33$, $p = .14$, $\eta^2 = .09$) or interactions with Familiarization Type ($p > .28$). Separate group analyses for the group with larger vocabularies show similar effects of Familiarity across Familiarization Type: a broadly distributed main effect in the Segmentation condition ($F(1, 12) = 4.78$, $p = .049$, $\eta^2 = .29$), but a main effect only over left frontal electrodes in the Memory condition ($F(1, 12) = 6.48$, $p = .026$, $\eta^2 = .35$). The relationship between speech segmentation ability and receptive vocabulary size at either 12 or 24 months also stays significant ($r = -0.54$, $r^2 = 0.29$, $p = .003$; $r = -0.47$, $r^2 = 0.22$, $p = .014$, respectively).

Table 2 *Correlation coefficients matrix for speech segmentation ability (and memory ability) at 10 months, and subsequent language scores for CDI subscales at 12 and 24 months. The ERP correlates of speech segmentation and memory ability are calculated by subtracting the mean amplitude for familiarized–unfamiliarized words over left frontal electrodes, with the more negative the value, the larger the effect of familiarity. For each measure the mean and the range are given as well*

Age	Measure	1.	2.	3.	4.	5.	6.	7.
10 months	0. Segmentation ability (-1.7 μV, [-24.0, +17.9])	−.036	−.564 **	−.588***	−.551**	−.151	−.518**	−.383*
	1. Memory ability (-3.8 μV, [-19.8, +7.1])		+.076	−.017	+.086	+.024	−.142	−.108
12 months	2. Items understood (93.0, [2–264])			+.875***	+.998***	+.308	+.585***	+.426*
	3. Phrases understood (14.9, [2–31])				+.845***	+.323	+.741***	+.608***
	4. Words understood (78.1, [0–233])					+.301	+.556**	+.396*
	5. Words produced (5.5, [0–39])						+.361	+.375*
24 months	6. Words understood (416.5, [149 – 681])							+.861***
	7. Words produced (326.4, [28 – 676])							

*$p \leq .05$; ** $p \leq .01$; *** $p \leq .001$.

Speech segmentation ability at 10 months and language ability at 12 and 24 months

Table 2 displays correlations between the ERP index of speech segmentation ability at 10 months and raw scores on the Infant and Toddler CDI subscales. At 12 months, there is a linear relationship between the segmentation index and the two subscales concerning language comprehension: The larger the ERP difference, the more items the infant understands. Speech production at 12 months, however, correlates neither with the ERP index of speech segmentation ability nor with the receptive language scales.

The index of speech segmentation ability is furthermore related to comprehension vocabulary at 24 months ($r = -0.54$, $r^2 = 0.29$, $p = .027$), as is shown in Figure 3b. The larger infants' ERP difference at 10 months, the larger their comprehension vocabulary at age 2. The ERP index of the memory condition does not relate to vocabulary size at 24 months.

Discussion

The on-line ERP measure has allowed us to see that infants can recognize words that they have heard just once before, either in isolation or in an utterance. We have shown, on the one hand, that a single exposure to a word spoken in isolation suffices for 10-month-olds to recognize it when it re-occurs; this effect was reliable across our 10-month-old group. On the other hand, we have shown that at least some 10-month-olds can show a similar recognition response when the first presentation of a word was embedded in a sentence. Such a response indicates that the sentence, heard for the first time, has been segmented into its component words and the words successfully stored for subsequent recall. Not all infants, as we showed, can perform this task at 10 months. But for those who can, the ability foreshadows early development of language skills.

The second contribution of our study is the demonstration of this relationship. Infants who at 12 months had higher vocabulary sizes turned out to be those who at 10 months had indeed succeeded in the utterance segmentation task. This was also visible at an individual level: The size of the familiarity negativity in the segmentation condition was significantly correlated with receptive vocabulary size at 12 months. At 2 years, the relationship between this index of speech segmentation skill and receptive vocabulary scores was still clearly visible.

Productive vocabulary size at 12 months did not correlate with this familiarity effect or with any other language measure. Bates, Dale and Thal (1995) argue that word production in infants this young is not a stable measure for language proficiency, since the variability in productive vocabulary size in infants under 13 months is not equivalent to the variability in receptive vocabulary size. Infants in our study indeed display less variability in number of words produced than words comprehended at 12 months (Brown-Forsythe test, $F = 31.01$, $p < .001$). Note that our index of speech segmentation skill is in fact significantly related to productive vocabulary scores at 24 months (when vocabulary expansion is in place).

The speech segmentation signature in our study is a negative familiarity effect for words previously presented in continuous speech. Other infant studies on isolated word processing also report a negativity comparing known/familiar with unknown/unfamiliar words (13- to 17-month-olds: Mills, Coffey-Carina & Neville, 1997; 9- to 11-month-olds: Thierry & Vihman, 2008). We propose that in our study this effect arises from the familiarity of word forms, and hence reflects the segmentation that has made the recognition response possible. Although Mills, Plunkett, Prat and Schafer (2005) demonstrated that for 20-month-olds this negativity is sensitive to word meaning rather than to word familiarity, it is plausible that at an earlier stage the same recognition mechanism is involved in detecting word-form repetition, so that (the meanings of) words could be learned. Our finding that the observed familiarity effect is linked to later vocabulary development is consistent with such an interpretation.

Another reason for relating the word familiarity effect to initial word-form learning comes from studies of artificial-language learning in adults, where an N400-like enhanced negativity for familiarized words is also reported (Abla, Katahira & Okanoya, 2008, Cunillera, Toro, Sebastián-Gallés & Rodríguez-Fornells, 2006; Sanders, Newport & Neville, 2002). Its distribution sometimes differs from the classical posterior N400 and is more similar to the familiarity effect's distribution in our study; it is a fronto-central negativity, associated with the on-line creation of word-like representations (Abla *et al.*, 2008; Cunillera *et al.*, 2006). The timing, too, is similar to the one we observed, though with a smaller latency: varying from 200–500 ms (Sanders *et al.*, 2002) to 300–500 ms (Abla *et al.*, 2008; Cunillera *et al.*, 2006). This negativity in artificial-language studies contrasts with the finding that word repetition in adults is generally coupled with a positive amplitude, both for native and for non-native speakers (e.g. Rugg, 1985; Snijders, Kooijman, Hagoort & Cutler, 2007). Nevertheless, the artificial-language evidence indicates that a negativity around 400 ms is involved in the learning of nonsense word forms. Again, it is likely that the infant familiarity effect for familiarized versus unfamiliar word forms shares task characteristics with the learning of nonsense word forms from continuous speech by adults.

This infant familiarity effect is present in the easy (memory) condition for most children, but present in the difficult (segmentation) condition only for those who later develop higher vocabulary sizes. We did not observe a link of any later language measure to the familiarity effect in the memory condition. It could be that this is because infants performed at ceiling for the easy condition, thereby masking a possible relationship between memory ability and later language scores. However, if infants performed at ceiling, then there should be less between-participant variation in the easy condition than in the difficult one. Yet this was not the case: There was as much variation between infants in their memory ability as in their segmentation ability (Brown-Forsythe test, $F = 2.11$, $p = .15$). Hence, only the ability to segment speech, not a supporting skill such as memory, is the crucial factor in the relationship with later-obtained vocabulary sizes.

The ERP measure allowed us not only to investigate the amount of familiarization required, but also the time course of word recognition. In the segmentation condition, the word familiarity effect was calculated as the average amplitude over left frontal electrodes in the time window 200–650 ms, and this choice of time window was based on the main effect that appeared there in the memory condition, across subjects. Comparing the effect amplitude across infants with different vocabulary size might then presuppose that the effect would have the same time course and distribution for all, but this does not have to be the case. As we have seen, infants with lower vocabulary sizes display a familiarity effect in the memory condition that starts earlier but also ends earlier. Moreover, their familiarity effect is more broadly distributed compared to their peers with greater vocabularies, who show a focal effect restricted to left frontal electrodes. Mills *et al.* (2005) also observed that distribution differences (broad ERP effects versus effects localized to left temporal and parietal electrodes) in infants were linked to vocabulary. Infants showing a familiarity effect only on left temporal and parietal electrodes understood relatively more words, whereas infants with a broader effect understood less words. They suggested that a focal left hemisphere distribution is linked to faster learning rates, and not to changes in brain maturation or reorganization. This suggestion was supported by results of Conboy and Mills (2006) with bilingual 19–22-month-olds: The same infants showed a focal familiarity effect for words from their dominant language but a broad familiarity effect for words from their non-dominant language. The differences in distribution and time course of the familiarity effect for the memory condition between infants with lower and higher vocabulary scores in the present study suggest therefore that these reflect differences in word-form recognition. Infants with lower vocabulary sizes might detect word repetition faster, but use more resources to do so, whereas infants with higher vocabulary sizes require fewer resources to do this, but show an extended recognition response. Recall that both groups display a familiarity effect for the first stage of this time period (200–500 ms), but that only infants with greater vocabularies continue to show the effect for the later stage (500–650 ms). It is possible that the extended response from 200 to 650 ms in the latter group reflects an additional stage: After an initial recognition response shared with the LV group, infants from the HV group then continue, for instance, to update the memory trace further or start a search for this word in their lexicon.

Note moreover that the time course of the familiarity effect for infants in the HV group is similar across conditions. In the segmentation condition we also observe a small negative familiarity effect from 200 to 500 ms, which further increases from 500 to 650 ms. There is a difference, though, in distribution: The effect is local in the easier memory condition, but more broadly distributed in the difficult segmentation condition. Whereas the HV infants show a more focal familiarity effect than their peers in the memory condition, they show a broader familiarity effect in the segmentation condition. This makes sense if we assume that a broader distribution of the familiarity effect reflects allocation of more resources needed to achieve word recognition in a difficult situation. Hence, 10-month-olds with greater vocabularies allocate more resources to achieve word recognition from one occurrence in continuous speech, while their smaller-vocabulary peers show no recognition response here at all; for those infants, even the memory condition demands large resource allocation.

Our results are thus consistent with the hypothesis of a link between early speech segmentation skill and later language development (Newman *et al.*, 2006). This link can be seen in group data, but also, as we have now demonstrated, at an individual level. How precisely does such a relationship arise? One way could be that infants who can segment words from sentences at 10 months have, even at that age, greater vocabularies, so that they could use familiar words to segment and recognize adjoining, previously unfamiliar words (Bortfeld, Morgan, Golinkoff & Rathbun, 2005). Infants with smaller vocabularies would then have fewer such possible anchors in the speech stream. Note that more extensive vocabularies at 10 or at 12 months do not need to come from advanced speech segmentation skill: Parents could produce words in isolation more often (Brent & Siskind, 2001). With an initial vocabulary built from hearing isolated word tokens, infants could then continue to bootstrap their segmentation abilities (Gambell & Yang, 2005).

In our study, however, the words preceding the target words in the sentences were varied (type–token ratio of 45/80 and 46/80, for Lists A and B respectively), and consisted for a large part of adjectives (List A: 42 adjectives, 32 determiners, three verbs, one pronoun, one adverb, and a noun; List B: 32 determiners, 29 adjectives, eight adverbs, seven verbs, and four pronouns). The first words that infants from Western cultures acquire are mainly nouns; predicates (verbs and adjectives) tend to be acquired much later (Bates *et al.*, 1995; Gentner, 1978). Hence, for both the LV and the HV group alike, the words preceding the target words were often unknown and could therefore not be used as an anchor to mark novel word onset. The syllabic structure of these words, on the other hand, could have been a cue for the onset of subsequent words. Although the largest part of the preceding words in both lists comprised monosyllabic words (List A: 40 words, List B: 50 words; mainly denoting functors), a substantial part of the preceding words consisted of bisyllabic words, all of which followed the strong–weak stress pattern typical of Dutch (List A 33 strong–weak words, List B 25 strong–weak words; mainly content words). More importantly, the target words themselves were all bisyllabic strong–weak words. As Kooijman *et al.* (2005, 2009) showed, Dutch infants at this age use this typical stress pattern as a cue for segmentation. Other powerful cues that infants are known to be able to use at this age, and which can be relevant for segmentation, include phonetic sequence probability (Mattys *et al.*, 1999; Saffran *et al.*, 1996), phonotactic constraints on word-internal sequences (Friederici & Wessels, 1993), and the presence of determiners, with their high frequency of occurrence (Shi & Lepage, 2008). Adult listeners use a variety of speech segmentation cues in combination, including both absolute cues such as phonotactic rules and the probabilistic cues such as distribution of stress patterns, phonetic transitional probability, and frequency of occurrence. The infants in our higher achievement group could be capable of achieving such a combination and applying it to segmentation, even if they knew none of the target words being presented.

We thus suggest that the most likely interpretation of our results is that segmentation skill itself, in the form of exploitation of whatever cues the speech signals offer to enable word boundaries to be found, is the functional link to later vocabulary growth. Segmentation produces immediate payoff in identification and recognition of words. Note that this does not mean that speech segmentation skill is the only factor that predicts future vocabulary size. Word learning and speech segmentation skill share many common correlates, from parental education and family socioeconomic status to auditory acuity and genetic endowment. All of these could influence the course of any aspect of language development. On socioeconomic and parental factors, there was little variation across our infant subject population, but there is always room for variation in ability across individuals.

In summary, the skill of segmenting words from continuous speech allows infants to identify candidate word forms, and store them for potential later recognition. Thus it is vital for building a vocabulary, and hence directly related to later language development. Infants hear continuous speech in the first year of life; it is their only resource for initial word learning. If they cannot segment it, vocabulary initiation will be hindered. This study provides evidence that even a single occurrence of a word form can, when this skill is in place, support subsequent recognition, and it also provides evidence of the link between the presence of segmentation skill and the development of a vocabulary: Infants who at 10 months rapidly recognize words from continuous speech go on to develop larger vocabularies than their peers, at least to the age of 2 years.

References

Abla, D., Katahira, K., & Okanoya, K. (2008). On-line assessment of statistical learning by event-related potentials. *Journal of Cognitive Neuroscience*, **20**, 952–964.

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

Bates, E., Dale, P.S., & Thal, D. (1995). Individual differences and their implications for theories of language development. In P. Fletcher & B. MacWhinney (Eds.), Handbook of child language (pp. 96–151). Oxford: Basil Blackwell.

Brent, M., & Siskind, J. (2001). The role of exposure to isolated words in early vocabulary development. *Cognition*, **81**, B33–B44.

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

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Papers and Reports on Child Language Development*, **15**, 17–29.

Conboy, B.T., & Mills, D.L. (2006). Two languages, one developing brain: event-related potentials to words in bilingual toddlers. *Developmental Science*, **9**, F1–F12.

Cunillera, T., Toro, J., Sebastián-Gallés, N., & Rodríguez-Fornells, A. (2006). The effects of stress and statistical cues on continuous speech segmentation: an event-related brain potential study. *Brain Research*, **1123**, 168–178.

Cutler, A. (2002). Native listeners. *European Review*, **10**, 27–41.
Cutler, A., & Carter, D.M. (1987). The predominance of strong initial syllables in the English vocabulary. *Computer Speech and Language*, **2**, 133–142.
Fenson, L., Dale, P., Reznick, J., Bates, E., Hartung, J., Pethick, S., & Reilly, J. (1993). MacArthur Communicative Development Inventories. San Diego, CA: Singular.
Fernald, A. (1985). Four-month-old infants prefer to listen to motherese. *Infant Behavior and Development*, **8**, 181–195.
Friederici, A.D., & Wessels, J.M. (1993). Phonotactic knowledge of word boundaries and its use in infant speech perception. *Perception & Psychophysics*, **54**, 287–295.
Friedrich, M., & Friederici, A.D. (2005). Phonotactic knowledge and lexical-semantic processing in one-year-olds: brain responses to words and nonsense words in picture contexts. *Journal of Cognitive Neuroscience*, **17**, 1785–1802.
Gambell, T., & Yang, C. (2005). Mechanisms and constraints in word segmentation. Unpublished Manuscript, Yale University.
Gentner, D. (1978). On relational meaning: the acquisition of verb meaning. *Child Development*, **49**, 988–998.
Goyet, L., de Schonen, S., & Nazzi, T. (2010). Words and syllables in fluent speech segmentation by French-learning infants: an ERP study. *Brain Research*, **1332**, 75–89.
Houston, D., & Jusczyk, P. (2003). Infants' long-term memory for the sound patterns of words and voices. *Journal of Experimental Psychology: Human Perception and Performance*, **29**, 1143–1154.
Junge, C.M.M., Cutler, A., & Hagoort, P. (submitted). Relating recognition efficiency for word forms at 10 months and for word meaning at 16 months.
Junge, C.M.M., Hagoort, P., Kooijman, V., & Cutler, A. (2010). Brain potentials for word segmentation at 7 months predict later language development. in K. Franich, K.M. Iserman & L.L. Keil (Eds.), BUCLD 34: Proceedings of the 34th Annual Boston University Conference on Language Development. Somerville, MA: Cascadilla Press.
Jusczyk, P., & Aslin, R.N. (1995). Infants' detection of the sound patterns of words in fluent speech. *Cognitive Psychology*, **29**, 1–23.
Jusczyk, P., & Hohne, E.A. (1997). Infants' memory for spoken words. *Science*, **277**, 1984–1986.
Jusczyk, P., Houston, D.M., & Newsome, M. (1999). The beginnings of word segmentation in English-learning infants. *Cognitive Psychology*, **39**, 159–207.
Kooijman, V.K., Hagoort, P., & Cutler, A. (2005). Electrophysiological evidence for prelinguistic infants' word recognition in continuous speech. *Cognitive Brain Research*, **24**, 109–116.
Kooijman, V.K., Hagoort, P., & Cutler, A. (2009). Prosodic structure in early word segmentation: ERP evidence from Dutch 10-month-olds. *Infancy*, **14**, 591–612.
Kuhl, P.K. (2004). Early language acquisition: cracking the speech code. *Nature Reviews Neuroscience*, **5**, 831–843.
Männel, C., & Friederici, A.D. (2010). Prosody is the key: ERP studies on word segmentation in 6- and 12-month-old children. *Journal of Cognitive Neuroscience Supplement*, 261.
Mattys, S., Jusczyk, P., Luce, P., & Morgan, J. (1999). Phonotactic and prosodic effects on word segmentation in infants. *Cognitive Psychology*, **38**, 465–494.
Mills, D., Coffey-Carina, S.A., & Neville, H.J. (1997). Language comprehension and cerebral specialization from 13 to 20 months. *Developmental Neuropsychology*, **13**, 397–445.
Mills, D., Plunkett, K., Prat, C., & Schafer, G. (2005). Watching the infant brain learn words: effects of language and experience. *Cognitive Development*, **20**, 19–31.
Morgan, J. (1996). Prosody and the roots of parsing. *Language and Cognitive Processes*, **11**, 69–106.
Newman, R., Bernstein Ratner, N., Jusczyk, A., Jusczyk, P., & Dow, K. (2006). Infants' early ability to segment the conversational speech signal predicts later language development: a retrospective analysis. *Developmental Psychology*, **42**, 643–655.
Rugg, M. (1985). The effects of semantic priming and stimulus repetition on event-related potentials. *Psychophysiology*, **22**, 642–647.
Saffran, J.R., Aslin, R.N., & Newport, E.L. (1996). Statistical learning by 8-month-old infants. *Science*, **274**, 1926–1928.
Sanders, L.D., Newport, E.L., & Neville, H.J. (2002). Segmenting nonsense: an event-related potential index of perceived onsets in continuous speech. *Nature Neuroscience*, **5**, 700–703.
Schreuder, R., & Baayen, R.H. (1994). Prefix stripping re-revisited. *Journal of Memory and Language*, **33**, 357–375.
Shi, R., & Lepage, M. (2008). The effect of functional morphemes on word segmentation in preverbal infants. *Developmental Science*, **11**, 407–413.
Snijders, T., Kooijman, V., Hagoort, P., & Cutler, A. (2007). Neurophysiological evidence of delayed segmentation in a foreign language. *Brain Research*, **1178**, 106–113.
Thierry, G., & Vihman, M. (2008). The onset of word form recognition. In A.D. Friederici & G. Thierry (Eds.), Early language development: Bridging brain and behaviour (pp. 115–135). Amsterdam: John Benjamins.
van de Weijer, J. (1998). Language input for word discovery. PhD Dissertation, Radboud University Nijmegen. MPI Series in Psycholinguistics 9.
Waxman, S., & Lidz, J.L. (2002). Early word learning. in D. Kuhn & R. Siedler (Eds.), Handbook of child psychology (6th edn., pp. 299–335). Hoboken, NJ: Wiley.
Woodward, J., & Aslin, R.N. (1990). Segmentation cues in maternal speech to infants. Paper presented at the 7th International Conference of Infant Studies Montreal, Canada.
Zink, I., & Lejaegere, M. (2002). N-CDIs: Lijsten voor Communicatieve Ontwikkeling. Aanpassing en hernormering van de MacArthur CDIs van Fenson et al. Leuven (Belgium)/Leusden (Netherlands): Acco.

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