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Ability to segment words from speech as a precursor of later language development: Insights from electrophysiological responses in the infant brain

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ABSTRACT

Infants' ability to recognize words in continuous speech is vital for building a vocabulary. Event-Related Potentials (ERPs) reveal a clear recognition response for familiarized words, relative to unfamiliar words, in 10-month-olds, but not consistently in seven-month-olds. We report three studies relating this ERP segmentation measure to later language development. First, seven-month-olds with ERPs similar to the 10-month-old norm displayed significantly higher language scores at three years of age than seven-month-olds with different ERPs. Second, 10-month-olds who recognized words previously presented once, within an utterance, later had larger vocabularies than 10-month-olds who could not perform this task. Third, infants who recognized words heard in continuous speech when they re-occurred in continuous speech outperformed infants who did not show this pattern on known-word recognition at 16 months. Hence, with a variety of measures, we see that the ERP segmentation effect serves as a robust predictor of the degree of later language development.

INTRODUCTION

The speech infants hear, in the first year of life before they themselves begin to speak, is mainly multi-word utterances, without clear pauses between the words [e.g., 1]. Thus to construct the initial vocabulary that they need to begin speaking themselves, infants need to learn how to segment words from speech. Indeed, Newman and colleagues [2] recently demonstrated that performance on speech segmentation tasks (but not on tasks measuring language discrimination or prosodic preference) is an effective predictor of expressive vocabulary at 24 months.

Word segmentation in infants has been principally studied with the behavioural two-stage familiarization-then-test version of the headturn-preference procedure (HPP; [3]). If infants first hear words in isolation, and then listen longer to passages containing these familiarized words compared to passages containing similar but unfamiliarized words, they have shown that they can segment individual words out of multi-word utterances. Subsequent research focused on the different, sometimes conflicting, sources of information in the speech signal that could serve as cues for segmenting words in their native language. These cues are probabilistic rather than fully reliable; no single cue is sufficient to detect word boundaries [4].

A disadvantage of the HPP, however, is that while it is evidence of the occurrence of word segmentation, it cannot reflect how rapidly this has appeared. Speech segmentation ability is measured in HPP by difference in looking times to passages containing occurrences of familiar words versus

passages containing occurrences of unfamiliar words. On-line segmentation measures, in contrast, can reflect the number of times a word needs to be heard before recognition appears. Kooijman and colleagues [5,6] were the first to construct an electrophysiological analog of the familiarization-and-test HPP paradigm, to obtain such an on-line measure of infant speech segmentation ability. They familiarized 10-month-olds with infrequent bisyllabic words by presenting them first 10 times, in isolation, and then recorded event-related potentials (ERPs) to these familiar words, and to matched unfamiliar words, in sentences. The 10-month-olds showed a negativity over left-frontal electrodes around 400 ms from onset of the familiar words, relative to the onset of unfamiliar words. This negativity appears to be quite stable for this age group: similar effects have been observed in other 10-month-old word-segmentation studies in our laboratory ([7], experiment 2 and 3 this paper), and in French 12-month-olds [8].

The timing of this effect shows that recognition of familiarized words starts as early as partway into the word. Kooijman [6] also used the same ERP design in a study of Dutch seven-month-olds, an age group for which there is no behavioural evidence that they are able to segment words from speech [9]. With ERPs, they found that seven-month-olds are able to recognize words in speech, although the group-averaged ERP for familiarity differed in polarity and distribution, compared to the first study. The majority of the seven-month-olds showed a positive effect of familiarity, although some showed the negativity typical for the 10-month-olds. Given that behavioural segmentation ability has been shown to predict later language development [2], can we also use this on-line measure of ERPs as a measure to predict future language

profiles? That is the topic of the present paper. We report three studies drawing a relationship between the ERP signal of speech segmentation discovered by Kooijman and colleagues (a negativity around 400 ms distinguishing familiar from unfamiliar words) and measures of later language development.

In our first experiment, we explore this issue by examining the relation between infants' ERPs for word segmentation at seven months and their later language profiles at three years. We hypothesize that those infants with ERPs similar to the 10-month-old norm will prove to exhibit higher language scores at the later time. In the following two experiments we study whether 10-month-olds are also able to recognize words in continuous speech under more difficult circumstances, and if so, how such recognition is related to future language profiles. The use of the on-line measure of ERPs allows us to test 10-month-olds' ability to recognize words in situations that better approach normal learning outside of the laboratory. Instead of a familiarization phase of ten isolated tokens, in Experiment 2 we reduce the familiarization phase to one word, embedded within an utterance. Infants have to spontaneously segment this utterance into words in order to show a recognition response upon second occurrence. In Experiment 3, the familiarization and test phase now both consist of novel utterances, instead of having one phase of isolated words, and the other of utterances.

For both studies we predict again a negativity for familiar words versus unfamiliar words, and a relation to later language development. To test whether this relation with later language development is indeed present, we measure vocabulary size at 12 and 24 months (for the second experiment), and performance in a preferential-looking study for known words at 16 months (for the third experiment). In other words, we use a variety of measures, allowing us to assess the robustness and generality of the relationship between the negativity as an ERP effect of word segmentation, and later language development at different stages.

1. SEGMENTATION AT SEVEN MONTHS

With the ERP design described above, Kooijman and colleagues tested both 10- and seven-month-olds' ability to recognise familiarized words in continuous speech [5,6], but they found different effects for the two age groups. Whereas for the 10-month-olds recognition was manifested as a left negativity for familiar words relative to unfamiliar words, for the majority of the seven-month-olds it was manifested as a right-frontal positivity. This shows that seven-month-olds are able to recognize words from speech, but that the underlying brain response differs from that of their older peers. Figure 1 illustrates the differences between the two age groups.

There were some seven-month-olds, however, who showed a pattern similar to that of 10-month-olds. Is this variability in ERP responses for word recognition then also related to later language development? To answer this question, 23 (11 girls) out of the 28 infants who participated in the seven-month-old study [6] returned to participate in standardized language testing [10,11]. The measure of speech segmentation ability in the present study differs from that of Newman and colleagues' study [2] in several respects: our infants are as young as seven months, they have Dutch as their native language, and their segmentation skill was tested with ERPs rather than with behavioural methods. When the infants returned for testing, they were on average 36 months old (sd 5.7 months). We obtained language quotients (LQs) for comprehension (mean 115.4; sd 11.8), for sentence production (mean 113.9; sd 14.7) and for expressive vocabulary (mean 118.9, sd 11.2). We subsequently divided the infants into two

groups, depending on the average polarity on left-frontal electrodes in the 350 – 450 ms time window at seven months. There were nine "Negative responders" (three girls), whose individual ERP effect of familiarity resembled that of 10-month-olds, and 14 "Positive responders" (eight girls), whose individual effect resembled that of the overall seven-month-olds. The smaller plots in Figure 1 demonstrate this.

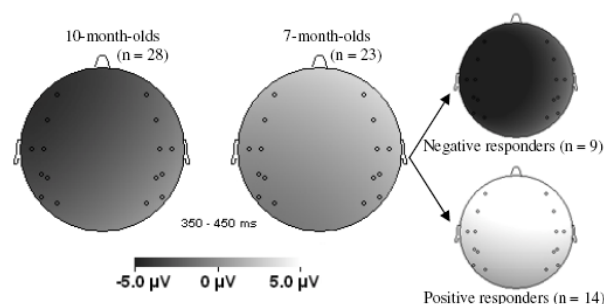


Figure 1: Mean distribution plots for the ERP effect of familiarity (familiar – unfamiliar words) in the 350–450 ms time window for 10- and seven-month-olds. The two smaller plots show the two seven-month-old subgroups.

Figure 2 shows that the children who at seven months show ERPs similar to those of their older peers (Negative Responders) have significantly higher LQs for comprehension ($t(21) = -2.37, p = .027$) and for word production ($t(21) = -5.85, p < .001$), as well as almost significantly higher LQs for sentence production ($t(21) = -2.06, p = .052$), compared to children who at seven months follow the overall group pattern (Positive Responders). Although all children fell within the normal or higher range of language skills, the Negative responders perform on average at 1.5 standard deviations above the LQ mean.

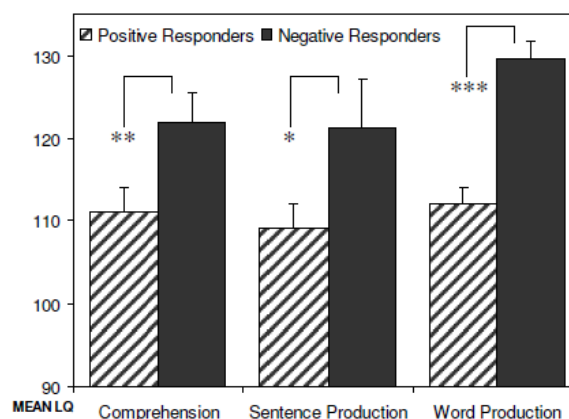


Figure 2: Language quotients at three years split by group performances at seven months: Negative responders have consistently higher LQs than their peers ($p < .001$ * $p < .05$ * $p < .06$; error bars are one standard error from the mean).**

Further, across all 23 subjects, there was a significant correlation between the ERP effect of familiarity and the LQ for word production: the more negative the difference wave between familiarized and unfamiliar words at seven months, the higher the LQ for word production at three years ($r_{\text{bivariate}} = -.45, p = .02$; with LQs for comprehension and sentence production partialled out, $r_{\text{partial}} = -.42, p = .06$). Together, these results show that ERPs for word recognition in continuous speech at seven months are related to later language development: Negative responders have higher language scores than Positive responders. This is most prominent for expressive vocabulary scores at three years.

2. SPONTANEOUS SEGMENTATION OF SPEECH AT 10 MONTHS

With ERPs as an established on-line measure for speech segmentation, we can now further investigate the amount of familiarization required before recognition appears. In the present study we reduce the familiarization phase to just one exposure. This word occurs within an utterance, to better resemble the natural learning situation, in which infants mainly hear continuous speech [e.g., 1]. Following this utterance, infants hear a word in isolation that either has or has not occurred in the previous utterance. In contrast to the situation in the previous studies, where recognition was based on a memory trace of forms heard repeatedly in isolation, in the present situation recognition is based on a memory trace of a form heard once in sentence context. Construction of such a trace requires that infants spontaneously segment the familiarization utterance into its component words. Can 10-month-olds succeed in such spontaneous segmentation, and subsequently classify a word as familiar or unfamiliar? Based on our previous findings [5-8] we predict a similar negative effect of familiarity in ERPs.

Even if segmentation ability is in place, however, immature verbal memory capacity could lead to absence of significant effects. We thus incorporated a control condition to test for infants' ability to recognize words when segmentation was not needed; that is, we included a memory condition in which the familiarization phase consisted only of the target word, excised from the utterance. Finding an effect of familiarity in the memory condition excludes the possibility that any null effect in the segmentation condition is due to immature memory capacities. See Table 1 for an example of both conditions. For the memory condition we also predict a negative ERP response of familiarity, but, based on responses for isolated words in the familiarization phase [5-7], with a bilateral anterior distribution and a shorter latency than the response predicted in the segmentation condition.

Table 1. Example of the two conditions, using the word pair 'hommel'-'mammoet'. Familiarization and target words are in italics, with the English equivalent in brackets.

Condition		Familiarization phase	Test phase
Memory	familiar	<i>hommel</i> (bumblebee)	<i>hommel</i> (bumblebee)
	unfamiliar	<i>hommel</i> (bumblebee)	<i>mammoet</i> (mammoth)
Segmentation	familiar	Een kleine <i>hommel</i> zit op het gordijn (a small bumblebee sits on the curtain)	<i>hommel</i> (bumblebee)
	unfamiliar	Het is een oude <i>hommel</i> met gele strepen (It's an old bumblebee with yellow stripes)	<i>mammoet</i> (mammoth)

Twenty-eight healthy 10-month-olds (13 girls) participated in this experiment. Figure 3 shows the results for both the memory condition and the segmentation condition. The top panel shows that for the memory condition, the positivity of ERPs for familiar words is clearly reduced compared to ERPs for unfamiliar words; in other words, we see the predicted negativity for familiar words versus unfamiliar words. This is significant for the 200-600 ms time window after word onset ($F(1,27) = 4.808$, $p = .037$, $\eta^2 = .15$) in the window 200-600 ms from word onset, with a similar latency and anterior distribution as the familiarization phases in previous studies [5-7]. Clearly, 10-month-olds are able to recognize words after a single exposure to the word in isolation.

For the segmentation condition, however, the same infants do not show such a recognition effect. Although visual inspection shows that there was a small time window where the

waveforms slightly diverge (with that of the familiar word being, as predicted, more negative), this was not significant. In the time window 400-600 ms, response to the familiar word was more negative compared to that to the unfamiliar word. There was however no significant main effect of Familiarity ($F(1,27) = 1.047$, $p = .315$, $\eta^2 = .04$), nor did this effect reach significance ($p < .05$) in any of the separate quadrants (left frontal: ($F(1,27) = 1.900$, $p = .179$, $\eta^2 = .06$); right frontal: ($F(1,27) = 0.167$, $p = .686$, $\eta^2 = .01$); left posterior: ($F(1,27) = 1.125$, $p = .298$, $\eta^2 = .04$); right posterior: ($F(1,27) = 0.597$, $p = .446$, $\eta^2 = .02$). Hence, we cannot conclude that 10-month-olds are generally able to spontaneously segment a word from continuous speech, because in neither time window did we observe a significant effect of familiarity.

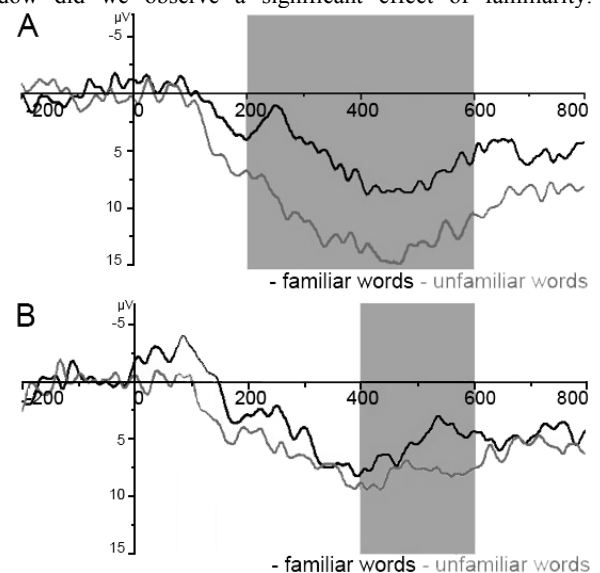


Figure 3: Grand average waveforms for familiar and unfamiliar words at left-frontal electrode F7 for (a) the memory condition and (b) for the segmentation condition; negativity is plotted upwards; 0 ms indicates word onset. The grey areas indicate the analysed time windows.

Although there was no overall pattern that showed that infants at ten months were able to spontaneously segment words from speech and recognize them upon further occurrence, the majority of the infants (17 out of the 28 infants) here displayed the expected effect of familiarity, with a similar polarity and left-frontal distribution, yet slightly later latency. How does this negativity of word familiarity relate to these infants' later language development? We predict those infants who show this pattern to have higher language scores than those who do not show this pattern, just as we have seen in the previous experiment.

We thus followed up each infant's language development at 12 and 24 months, using a Dutch version of the MacArthur-Bates Communicative Development Inventory [12, 13]. Compared to the standardized language tests in the previous experiment, we now asked the parents to fill in check-lists about their child's language profiles. Language skills were assessed in 12-month-olds using the Infant-CDI 'Words and Gestures', and in 24-month-olds using the Toddler-CDI 'Words and Sentences'. The Infant-CDI, for ages eight to 16 months, assesses vocabulary comprehension and production of 434 typical infant words divided over 17 semantic categories. The Toddler-CDI, for ages 16 to 30 months, also assesses vocabulary comprehension and production (702 words divided over 22 semantic categories). It further has five subscales measuring morphological and syntactic development. Two of these sections, mean length of three longest sentences (MLU) and grammatical complexity, were used in this study.

Correlations were next calculated between size of the negative familiarity effect in the segmentation condition and later language scores. At 12 months, segmentation ability correlates significantly with comprehension vocabulary size ($r = -0.616$, $r^2 = 0.38$, $p < 0.001$): the more negative the difference wave, the more words and phrases the infant understood at twelve months, as Figure 4 demonstrates. Although infants with a stronger segmentation ability also tend to produce more words and non-linguistic communicative gestures, these relationships are not significant ($p > .06$). One year later, at 24 months, speech segmentation ability is now also related to expressive vocabulary ($r = -0.417$, $r^2 = .17$, $p = .027$), as Figure 4 furthermore shows. Clearly, infants with better segmentation ability at 10 months have larger vocabularies at age two. Moreover, at age two they also make more complicated sentences ($r = -0.375$, $r^2 = .14$, $p = .049$), albeit not longer ones. The ability to spontaneously segment words from continuous speech, as manifested by a negative ERP effect of familiarity around 400 ms, is an important precursor of language development up to two years. Although not all infants showed this response as early as 10 months, those who did went on to develop larger vocabularies.

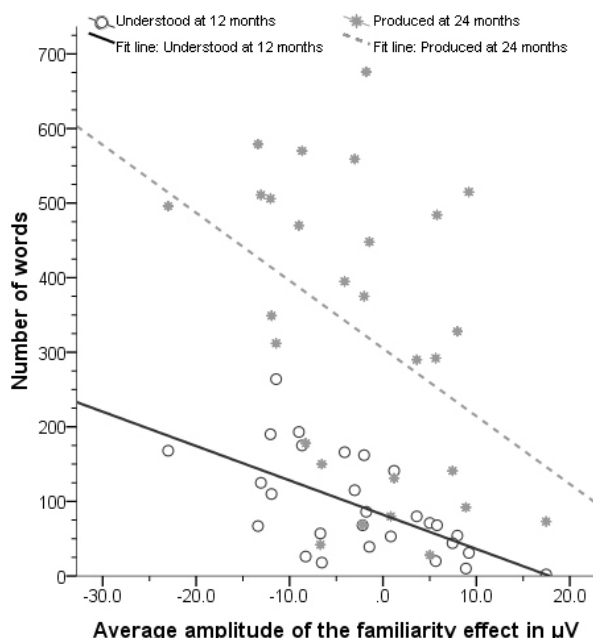


Figure 4: Relation between segmentation ability at ten months, as measured by the individual amplitude difference (familiar-unfamiliar words in segmentation condition) over left-frontal electrodes in the time window 400-600 ms, and the number of words understood at 12 months or produced at 24 months, respectively.

3. RECOGNIZING WORDS FROM AND WITHIN CONTINUOUS SPEECH AT 10 MONTHS

When testing infants' ability to segment words from running speech, both HPP and ERP experiments used the typical familiarization-and-test paradigm, described in the introduction, where one phase consists of isolated words and the other of passages. Infants at 7.5 months of age can recognize words in continuous speech after hearing them in isolation as well as recognizing words in isolation after hearing them in passages [3]. Clearly, for either recognizing words in passages or building up a memory trace from passages, word segmentation skill is required. Nevertheless, in real life, infants hardly ever hear lists of repeated isolated words. The speech that infants hear in the first year of life predominantly consists of multiword utterances. This is even the case for infant-directed speech [1]. To approach the daily learning situation

better, we used ERPs to study now whether infants can segment words from continuous speech and recognize them in novel utterances. Can 10-month-olds build up a memory trace for words repeated over utterances that is sufficient to distinguish them, within a continuous speech stream, from unfamiliar words? We predicted a similar negative ERP response of familiarity as in our earlier studies.

To examine whether infants are able to segment words from continuous speech and recognize them in novel utterances, 36 healthy ten-month-olds (20 girls) listened to 20 blocks of 12 sentences. Per block, there was a familiarization phase of eight sentences in which an infrequent bisyllabic word was familiarized, followed by a test phase of four sentences, two with the familiarized word, and two with an unfamiliar word, in both cases in medial position. Table 2 shows an example of a block.

Table 2. Example of a familiarization-and-test block, using the word pair 'drummer'-'fakirs'. The familiar and unfamiliar words are in italics.

Familiarization Phase	
1	Meteen sloeg de <i>drummer</i> zijn slag
2	De stier ging de <i>drummer</i> volgen
3	Veel fans waren gek op de <i>drummer</i>
4	De grote trom was van de <i>drummer</i>
5	Hij was <i>drummer</i> van een band
6	Voor de <i>drummer</i> stond alles klaar
7	Elke band heeft een <i>drummer</i> nodig
8	De populaire <i>drummer</i> zong graag
Test Phase	
9	De leuke <i>drummer</i> hield van slagroom
10	De kleine <i>fakirs</i> zijn gegroeid
11	Die enge <i>fakirs</i> zijn magisch
12	Een goede <i>drummer</i> heeft werk

Note that due to the lower signal-to-noise ratio characteristic of ERP experiments, infants are presented with more familiarization and test combinations than HPP studies typically use; however, the amount of familiarization, eight utterances per block, is comparable to HPP studies. ERPs were collected and time-locked to the onset of the familiarized and unfamiliar words in the test phase. Subject individual's ERPs are extracted from the EEG signal by averaging over at least 10 artefact-free trials per condition (maximum is 40 trials), which are subsequently averaged over infants to obtain grand average waveforms.

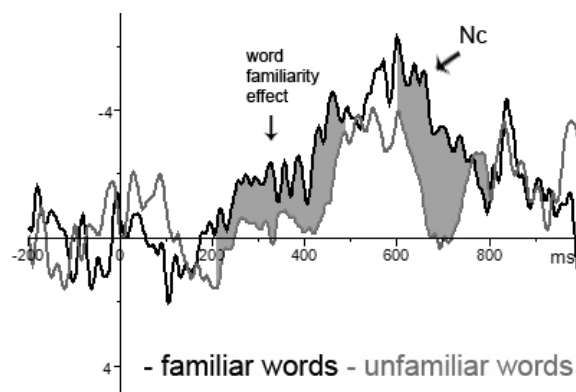


Figure 5: Grand average waveforms for familiar and unfamiliar words in the test phase at left-frontal electrode F3; negativity is plotted upwards; 0 ms indicates word onset. The grey areas indicate the analysed time windows.

Figure 5 shows the results for all infants. We observed two ERP effects. First, in the time window 200-500 ms we see our expected effect of familiarity, with familiar words eliciting a more negative brain response than unfamiliar words. The effect reaches significance, and is widely distributed over the head ($F(1,32) = 4.329$, $p = .055$, $\eta^2 = .12$). Since it is similar to earlier ERP effects of word familiarity [5, 6], we assume it reflects speech processing, in particular, the recognition of the familiarized word.

In a later time window, however, we observe again a negativity for familiar words compared to unfamiliar words. We think that this is not a continuation of the word familiarity effect, but rather an instance of the Negative Central component (Nc) effect [14]. The Nc-effect is not specific to language processing, but indexes domain-general processes such as attention and stimulus preference. Although the Nc-component was originally demonstrated when infants see a novel object compared to a familiarized object, the effect cannot be simply explained as a novelty effect: infants also elicit the Nc-component for their parents' faces compared to strangers' faces [15]. The Nc-component has also been elicited for auditory stimuli. ERPs to known versus unknown words, in 13-to-17-month-olds show both a negativity in the 200-350 ms time window as well as in the 600-900 ms time window [16]. Different functional significance has also been attributed to the two time windows: the N200-350 ms is supposed to index meaning, and the N600-900, as an instance of the Nc component, is linked to attentional processing. The timing and distribution of the two effects in our study suggest that they are similar to the Mills and colleagues' study [16]. We therefore believe them to have similar functional significance: the early effect reflecting the word familiarity effect, and the later effect reflecting the Nc-effect.

To test whether the word familiarity effect was once more related to later language development, the same infants participated in an intermodal preferential-looking eye-tracking task when they were 16 months. Here, the infants first played with two novel objects, which they later saw on a computer screen in isolation. They saw four clips of each, but only one object received a label (e.g., 'this is a tiek, a tiek, tiek!, do you see the tiek?'); and the other object was simply generally introduced (e.g., 'this is fun, great huh, yeah, do you see this?'). This is similar to the design in [17], where infants also see two novel objects equally often, but only learn the mapping of word and object for one object. Learning to map only one label to one object is supposedly easier to achieve than learning two labels for two objects (but see [18], who argues that infants might then transfer the label to the unnamed object). After this training, the test phase started. Here, infants saw pairs of objects and were asked to look at one of the objects (e.g. 'do you see the tiek?'). The pairs consisted either of the two novel images or of two images representing familiar words (e.g., a car and a ball). The clips lasted 5 seconds, with the target word being presented at 2.5 seconds. The dependent measure is the increase in looking time at the target word from 360 ms after the target word onset to the end of the clip, relative to the time window before this word starts ('baseline'). In the baseline window, infants are supposed to be at chance, but after the word is presented, they are supposed to orient more to the target word.

Figure 6 shows the overall results of the eye-tracking study. Although infants show the expected pattern for familiar words, with a mean of 8.2 % increase in looking at the target after hearing the word ($t(32) = 4.963$, $p < .001$), they do not show this pattern for the novel word processing ($t(32) = -1.481$, $p = .148$). In fact, even at baseline they have a significant preference for the unnamed object ($t(32) = -3.886$, $p =$

$<.001$), and when they hear the label, they increase their looks even more to the unnamed object.

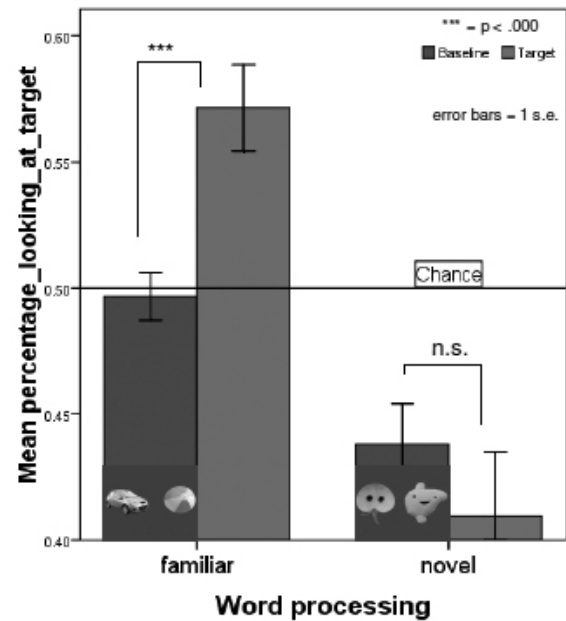


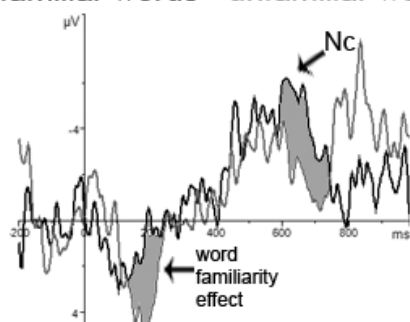
Figure 6: Infants' performance at 16 months for the eye-tracking task, split by familiar and novel-only trials.

This tendency to look away from the correct novel object is not significant, but it is clear that the results show no effect of infants having learned to match the novel label to the correct novel object. It is therefore not valid to equate infants' novel word processing skill with performance on novel word processing trials in this eye tracking task, because the baseline already suggests a preference for the un-named novel object, and it is therefore unclear what, if not the label, drives the motivation of the infants to look even more at the unnamed object in the test phase. Performance in the eye tracking task on familiar word processing, however, is a good measure for familiar word processing skill, because there is a valid baseline, and the majority of the infants show the expected increase after hearing the target word.

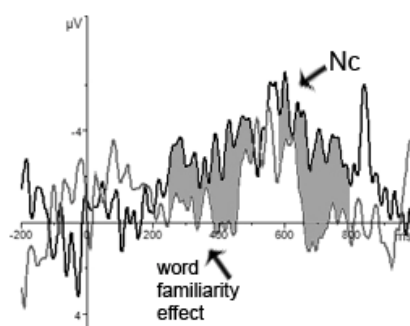
In order to study the relationship between performance at a speech segmentation task at 10 months, and subsequent familiar word processing skill at 16 months, we created two groups based on the average increase of looking time for familiar words. There were 15 infants (9 girls) with higher language skill, who on average increased their looking at the target by 16% (8 - 30%), and there were 18 infants (9 girls) with lower language processing skill, who on average only increased their looking at the target by 1.2 % (-10 - 7%). We subsequently returned to the ERPs of familiarity of these subgroups. Does familiar word processing skill at 16 months reflect speech segmentation skill at 10 months?

Figure 7 shows the average waveforms for familiar and unfamiliar words for both subgroups at left-frontal electrode F3. Infants with better language processing skill (top panel) start distinguishing familiar from unfamiliar words faster than their peers. There is a near-significant interaction between the two groups in the time window 140 - 230 ms ($F(1,30) = 3.579$, $p = .068$, $\eta^2 = .12$): for infants with better language processing skill, the word familiarity effect starts at the 140 - 230 ms time window ($F(1,14) = 4.746$, $p = .047$, $\eta^2 = .18$), whereas for infants with lower language processing skill this effect is not yet significant at that point ($F(1,16) = 0.195$, $p = .665$, $\eta^2 = .02$), but instead starts after 230 ms. For the Nc effect, however, both groups seem to display a similar latency.

- familiar words - unfamiliar words



Infants with higher language processing skill



Infants with lower language processing skill

Figure 7: Grand average waveforms in the test phase for familiar and unfamiliar words, at left-frontal electrode F3, by performance on familiar word processing at 16 months; negativity is plotted upwards; 0 ms indicates word onset.

Infants with better language skill at 16 months recognize familiar words faster and for a shorter amount of time than infants with poorer later language skill. This makes sense: processing the words for a shorter amount of time would facilitate processing of what comes next in the speech stream, which, in consequence, boosts their segmentation system, and hence their vocabulary acquisition. Once more, we see that speech segmentation ability is related to future familiar-word processing skill: those infants who at 10 months show an earlier word familiarity effect are the ones with better language processing skill at 16 months.

DISCUSSION

An issue in this paper was whether we can use a negative ERP effect for familiarized relative to unfamiliar words, termed here the word familiarity effect, as a measure for subsequent language development. Crucially, infants had to segment the speech signal into its component words to start recognizing these words as familiar. In all three experiments described above we observed a clear relationship between the presence of this negativity and future language profiles. On varying measures of later language development (standardized language tests, parental check lists, and on-line eye-tracking) and at multiple ages of return (from 12 to 36 months) we show that this ERP segmentation effect serves as a robust predictor of the degree of later language development.

Compare this to the Newman and colleagues' study [2], where they use a behavioural response of speech segmentation skill as the dependent measure. They could observe this significance of speech segmentation skill for later language development when they collapsed infants' performance over several of their studies. Thus had they only studied this relationship in one of their studies, it is entirely possible that the importance of speech segmentation might not have shown up due to lack of power. Hence, it seems that ERPs are able to

provide a highly sensitive measure of speech segmentation skill. Nevertheless, the word familiarity effect differs slightly in latency in each experiment. This itself increases the worth of ERPs as an on-line measure for speech segmentation: this measure allows us to see *when* recognition of familiarized words is in place. Infants who show this effect, and hence demonstrate that they have adequately segmented the speech signal, go on in early childhood to develop greater proficiency in a variety of language skills.

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