THE RELEVANCE OF EARLY WORD RECOGNITION:

INSIGHTS FROM THE INFANT BRAIN

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The relevance of early word recognition: Insights from the infant brain

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te Niedorp

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In particular I would like to thank first all the children and their parents who enabled me to answer -to some extent- the questions that are addressed in this thesis. Without their willingness to participate in the experiments I could never have managed to do this.

Then I would like to take this opportunity to thank my promotores Anne Cutler & Peter Hagoort, without whose support this research would certainly not have been possible either. Anne has been the most inspiring and enthusiastic supervisor I could have wished for, and at the same time was always supporting when I needed advice. Peter was always there to steer me in the right directions, and asking the right questions at the right time. Together, they gave me the opportunity to find my own way into research and pursue my own questions, which is a luxury I only now fully realize.

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The experiments in this dissertation were mainly carried out at the BRC, an interdisciplinary organization that involves researchers from the Psychology and Linguistics department from the Radboud University as well as from the MPI. Here, I have had the pleasure to work with many colleagues and friends and to thank them for sharing their expertise and opinions with me during the monthly meetings and the many conferences, and in the office, hallways, or canteen. A few people I would like to mention individually are Nienke Dijkstra, Nicole Altvater-Mackensen, Sabine Hunnius, Janny Stapel, Marlene Meyer, Helen Buckler, Sho Tsuji, and of course Angela Khadar. Also Titia Benders, another infant researcher from the University of Amsterdam, has been a great help. I furthermore thank my interns Jacobine Bos and Andrea Reiter for their contribution to this thesis. Nienke, I am very happy knowing that you will be standing by my side during the defense as my paranymph.

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After two and a half years working on my thesis at the MPI, I went abroad to spend four months at Bangor University to research speech segmentation skill in bilingual infants. Thanks to financial support of the ESRC Centre for Research on Bilingualism in Theory and Practice, and of the Wales Institute of Cognitive Neuroscience, I could work with Debbie Mills and her colleagues from the School of Psychology. It was a sheer pleasure to see how life is in another research group. Debbie, thank you so much for sharing all your knowledge with me and for giving me the opportunity to develop myself further in the field of developmental cognitive neuroscience. I hope we will collaborate even more in the future. I also would like to express my gratitude to the members of the Bangor Brain & Cognitive Development laboratory, in particular Nat Ebanks, Theresa Wildegger, and Emily Guilhem. Thanks to you, and thanks to Nick Oosterhof, you made my stay in Wales such an unforgettable experience.

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Finally I would like to thank Arent Pelster. I believe that you have contributed with your support and skill much more than the average partner of a PhD-candidate typically has done. Not only have you often unknowingly encouraged me to continue my academic career by explaining my infant research to your friends and have you allowed me to spend many weekend-hours on this dissertation, but you have also actively played a role in the research described here. You were often the first person to read and comment on what I had written. You designed the cover with me (on a sunny Sunday, of course). You painstakingly wrote many computer scripts to analyze the eye-tracking data in all the various ways I requested. Thank you. You make me very happy.

Caroline Junge

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* *Note on the cover:* There are two reasons why there are cows in the picture. As mentioned before, this research is partly a continuation of the research carried out by Valesca Kooijman, who investigated infants' ability to recognize word forms (without meaning). Her cover depicts a jagged coastline, mine depicts a stream with three cows. The first experimental chapter in this thesis, however, describes an experiment in which I investigated infants' ability to recognize words in the context of meaningful pictures. Hence, the meaning of words is now also examined in this dissertation. One of these words was 'cow', a typical Dutch animal. This brings us to the second reason. Normally one can never see on-line in the EEG what an infant is experiencing at that time. However, one of the first infants who participated in the word meanings experiment always showed a noticeably high frequency burst in his EEG every time a picture of a cow was presented on the screen. So afterwards I asked his mother whether her son had any interest in cows. She told me that they had just returned from a holiday in France, and that they had to stop every time they passed a meadow with cows, because her son simply adores them! Since then, I could occasionally see this increase of high frequency EEG in other infants, particularly when they saw pictures of other infants, or of food-related items, such as bottles.

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

TABLE OF CONTENTS

INTRODUCTION

CHAPTER 1

Infants learn their mother tongue remarkably easily, and at an impressive speed. Only a year after they are born infants generally start to speak their first words. Parents correctly consider this as a milestone in their infants' language acquisition. Yet language development is then long underway. In their first year of life, infants have already started to tune into their native language (for an overview see e.g., Kuhl, 2004; Saffran, Werker & Werner, 2006). Even at birth, infants already show a preference for their native language, compared to a language from a different rhythmic class (Mehler et al., 1988; Nazzi, Bertoncini & Mehler, 1998). By five months, infants can even differentiate between their native language and a language that is rhythmically very similar, such as between English and Dutch (Nazzi, Jusczyk & Johnson, 2000). This is also the time that they start to recognize their own name (Mandel, Jusczyk & Pisoni, 1995). Following these first native-language related steps, infants between six and 12 months become sensitive to the phonemic repertoire of the native language, while they lose sensitivity to non-native phonemic contrasts (Kuhl et al., 2008). At six months there is also the first experimental evidence that infants understand the meaning of words such as 'mommy' and 'daddy' (Tincoff & Jusczyk, 1999). By at least nine months infants have become sensitive to frequency, distribution and other statistical properties of the native language that will aid the process of language acquisition, particularly the ability to find words in the speech stream.

Nine months is also the age at which infants have begun building a (receptive) vocabulary: the average American-English nine-month-old is estimated to understand 15 words (Bates, Dale & Thal, 2002). However, building a vocabulary is not a trivial task. Learning the meaning of a word not only entails making a mapping between word and object, but crucially, also identifying both the object and word first. Neither of these processes is simple, since both the visual and the auditory world are rich environments, containing many possible candidates. Figure 1.1 illustrates this with a typical example of an event in an infant's daily life. In Figure 1.1A, we see a child carried by her mother, facing a camera (and another person holding the camera). In the background there is a table with two chairs, with among other things, two glasses of water, a bottle, and some cutlery. In Figure 1.1B, there is a spectrogram of the audio that the child might hear the mother say. If the child hears an utterance such as *Waar is je flesje nou? (*"Where's your bottle then?"), an appropriate response for the child would be to turn her head and look at the bottle, as is illustrated in Figure 1.1C. This would imply that she must be able understand the utterance to some extent as well as to act upon this understanding. In other words, she must map the word *flesje* ("bottle") from the speech stream to the concept BOTTLE that then matches the one on the table.

As the example in Figure 1.1B further shows, the child must recognize the word *flesje* as such, although this word is not uttered in isolation, but within a sentence. The corresponding spectrogram shows that the speech is continuous: There are no reliable or consistent pauses in the speech signal that mark word boundaries. Figure 4.1 (from Chapter 4) gives more examples of spectrograms of sentences that further illustrate the continuity of speech. The example utterance depicted in Figure 1.1B is illustrative of the language input that infants (and adults, too) normally hear: it consists mainly of multiword utterances (Morgan, 1996; Van de Weijer, 1998; Woodward & Aslin, 1990). Consequently, in order to recognize words such as *flesje* in the speech stream, the infant must segment the utterance into word-like units. How do children then learn where words begin and end if they do not yet know any words? This is known as the 'speech segmentation problem'. Yet infants must have largely solved this problem, since by twelve months they have a small vocabulary.

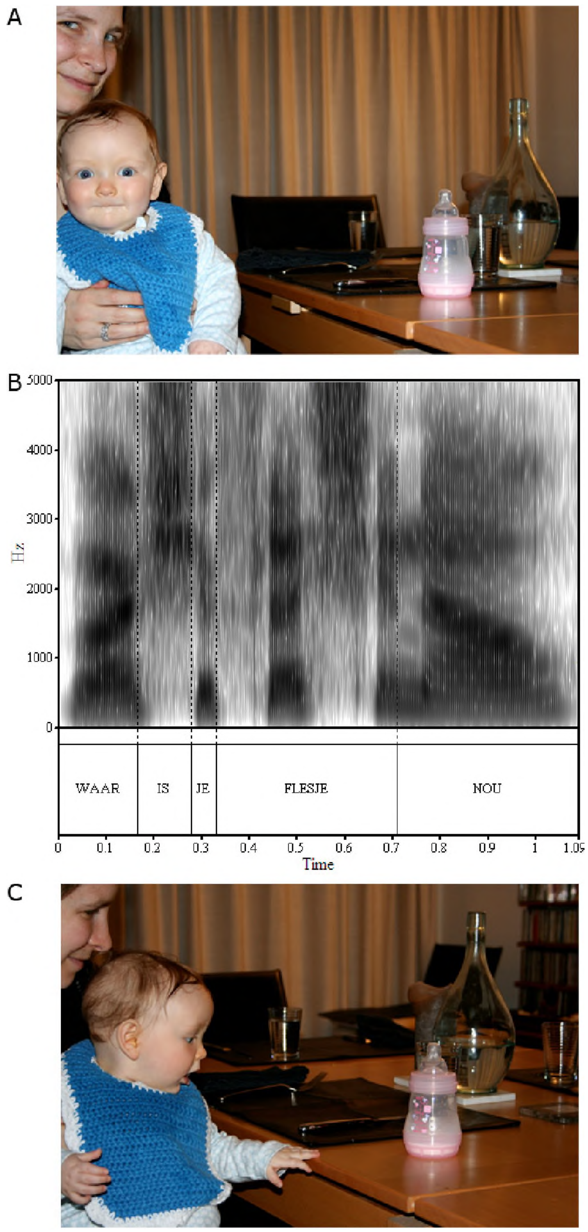

Figure 1.1: *Recognizing your own bottle ("flesje"), both in the visual (A) and in the auditory world (B), can be quite demanding.*

Another problem that infants face is that they must learn how to create abstract conceptual representations from the world they live in. Word learning after all involves mapping a word to an abstract concept. Thus, in our example the girl must map the recognized word *bottle* to her bottle standing on the table (i.e., and not to other entities in the present scene, or parts of the bottle, such as its rubber top, or the milk inside it). Successful word learning further requires the infant to extend the word *bottle* beyond this exemplar (i.e., including other bottles, such as the bottle of oil), but excluding objects that are not bottles. But how does a child learn what (the limits are that) a word refers to? This problem is known as the 'indeterminacy of translation' (Quine, 1956).

As Spelke (2000) noted, infants have already acquired an impressive repertoire of core conceptual knowledge during their first year. Some of these pre-linguistic concepts involve category-based relations such as ANIMAL, but infants can also focus on property-based relations such as shape or color, and on physical relations, such as support or containment (these physical relations are necessary if one wants to learn events that correspond to verbs). Infants are furthermore guided by expectations or constraints that help them to select the relevant entity. One of these constraints is the noun bias (Gentner, 1982) in which infants have a preference to map a novel word to an object rather than to an event or to a property. Another constraint is the whole-object assumption, in which a name is given to a whole object rather than to its salient part. The taxonomic assumption (i.e., the assumption that the same term can be applied to objects of the same kind) and the mutual exclusivity assumption (i.e., the assumption that novel names can only refer to objects whose names are yet unknown; Clark, 1987) also guide infants to select a correct candidate for a novel word. In addition, there are social, pragmatic and intentional constraints that influence word learning (cf. Tomasello, 2003).

In their second year of life, infants start to use words. They do not only start to produce words, but produce them with the right reference. The stage at which infants learn to speak their first 50 words is known as early word learning. Word learning in this stage is slow and hesitant, with one or two newly produced words per week (see e.g., Carey, 1978; Hollich, Hirsh-Pasek & Golinkoff, 2000).

Around 18 months, the rate at which infants produce new words dramatically increases (see e.g., Bates et al, 2002), a phenomenon also known as the 'vocabulary spurt'. Note, however, that the vocabulary spurt is defined in terms of changes in word production, not in word comprehension (Nazzi & Bertoncini, 2003). Shortly before their second birthday, infants start to combine words into two-word utterances. At this stage, infants already give evidence of being sensitive to the syntactic rules of the native language: whereas English children might say 'eat cookie' (i.e., verb-object), Dutch children will say 'koekje eten' (i.e. object-verb). By three years children have acquired the core grammatical rules and produce over 500 different words in their native language: They are well on their way to perceiving and producing their first language in an adult-like manner.

Topic of the dissertation

Once infants start to produce language, the path and pace of infants' first language acquisition are well documented (see for an overview, Clark, 2003; Gillis & Schaerlaekens, 2000, for Dutch). For instance, Schlichting (1996) asked 37 mothers to write down the first 50 words that their child actively produced. Although the variation was high between infants, not only in the age at which they learn their first words, but also in which words were learned first, there were certain words, particularly nouns, that a majority of mothers reported as words their child said first ('typical early words'), such as *auto* ("car"), *mamma* ("mommy"), *pappa* ("daddy") and *poes* ("cat"). Hence, the words that infants produce first typically refer to concrete, specific known exemplars or persons of high relevance to the individual child (Clark, 1993; Fenson et al., 1994). Yet comprehension precedes production. At 12 months, when there is clear evidence that infants now start to produce their very first words, American-English infants are estimated to understand already about fifty to seventy-five words (Bates et al., 1995; Fenson et al., 1994; Golinkoff & Hirsh-Pasek, 2006). Table 1.1 further illustrates this for Dutch infants: based on the typical early words reported in the diary studies, it compares the percentage of infants who produce this word as one of their first 50 words (Schlichting, 1996), with the percentage of 41 (other) infants who understand these words at 12 months (based on parental questionnaires obtained in Chapter 3, this dissertation). Although the words in Table 1.1 are sorted by word class and then by likelihood of word production, evidence from the parental questionnaires at 12-month-olds suggest that the typical early words present in infants' productive lexicons were also among the ones that infants understood first. However, the largely perceptual learning that necessarily precedes infants' first steps in language production is not so well documented, because it is more difficult to register how and when infants start to comprehend words than when they actively start to use these words. This is why this dissertation centers on receptive word learning in the period in life when infants start to understand their first words, i.e., between seven and 10 months.

To build a vocabulary, in summary, requires the following skills in infants: identifying a concept (categorization), identifying a word (recognizing words in a speech stream; speech segmentation), and mapping words to objects or events (word-to-world mapping; Waxman & Lidz, 2002). This dissertation examines the neural signatures of the skills required for early word learning, with a focus on speech segmentation. Since the variation between infants in their pace of language development is typically high, a further goal of this dissertation is to examine how individual differences during this pivotal period of life relate to present or future language states.

Table 1.1: *The most frequent early words in Dutch, according to diary studies concerning word production, with English equivalents in brackets.*

	% of infants who produce this as one of first words*	% of infants who omprehend this word at 12 months^		% of infants who produce this as one of first words*	% of infants who comprehend this word at 12 months^
Nouns			**Verbs**		
auto (car)	94.6	46.3	eten (eat)	54.1	80.5
mama (mummy)	86.5	95.1	zitten (sit)	45.9	29.3
papa (daddy)	86.5	87.8	slapen (sleep)	40.5	58.5
poes (cat)	81.1	43.9	poepen (defecate)	37.8	N.A.
opa (granddad)	73.0	48.8	drinken (drink)	35.1	58.5
koekje (cookie)	62.2	48.8			
oma (grandma)	62.2	53.4	**Social expressions**		
pop (doll)	59.5	26.8	bah (eeuw)	70.3	46.3
bal (ball)	56.8	97.6	dag (bye)	67.6	85.4
hond (dog)	48.6	53.7	nee (no)	64.9	82.9
jas (coat)	45.9	41.5	au (ouch)	59.5	36.6
klok (clock)	45.9	17.1	ja (yes)	56.8	61.0
eend (duck)	43.2	26.8	hap (bite)	40.5	N.A.
appel (apple)	37.8	29.3	boem(boom)	35.1	63.4
boek (book)	37.8	73.2	kiekeboe(peekaboo)	35.1	87.8
aap (monkey)	35.1	14.6			
kaas (cheese)	35.1	19.5	**Adverbs**		
			uit (out)	56.8	12.2
Other			op (on, done)	54.1	68.3
die (that)	56.8	34.1	buiten (outside)	35.1	26.8
			open (open)	35.1	24.4

Note. *) The sample consists of 37 infants whose mothers wrote down in a diary the first fifty words their children spoke (adjusted from Schlichting, 1996). ^) The sample consists of 41 different children whose parents filled in the N-CDI (Zink & Lejaegere, 2001) around their child's first birthday (obtained from data collected in Chapter 3). 'N.A.' = not available: this word was not on the parental questionnaire.

In this dissertation, processes of early word learning are predominantly examined via event-related brain potentials (ERPs). I will first explain why this method was chosen and then explain this method in more detail, before we turn to an outline for the remainder of the dissertation.

The ERP method

Since infants cannot tell us how they learn language, sophisticated methods have been developed to gain more insight in the developmental stages of language acquisition in preverbal infants. For instance, there are behavioral measures which rely on infants' natural inclination to turn their head in the direction of interesting stimuli, such as the widely-used head-turn preference procedure (HPP, Fernald, 1985) or the conditioned head-turn procedure (Werker, Polka & Pegg, 1997). Similarly, the visual fixation procedure also measures (another side of) attention: this method relies on infants' typical reaction to look away once he/she becomes bored with the visual display while a certain sound is repeatedly played, yet re-start looking once the sound is changed. ERPs, on the other hand, are a neurophysiological measure: They are averaged epochs of electrical signals generated by the brain, time-locked to a certain stimulus. Hence, this method delivers information about the neural correlates of cognitive processes, offering an on-line reflection of how the infant brain processes language.

There are several reasons why the ERP method was chosen in this dissertation to investigate receptive word learning over other (behavioral) methods appropriate for infants. The first advantage of ERPs, particularly in infant research, is that no overt response is required. Behavioral methods by definition measure overt changes in infants' behaviors in response to one or more types of stimuli. These changes in behavioral states reflect changes in attention (i.e., preference). For example, HPP measures looking time for one versus another type of stimuli (e.g., passages with familiar versus unfamiliar words). If infants look more in the direction of one stimulus type compared to that of another stimulus type, this is interpreted as infants' having a preference for the type that corresponds to the longer looking times; consequently, infants have distinguished between the two types of stimuli. Yet when infants do not show a preference for either type, one cannot be sure whether they do not differentiate between the two types, or whether they simply do not prefer one type more than the other. This makes it difficult to interpret null effects in infant behavioral research (Aslin & Fiser, 2005). ERPs, in contrast, are direct neural signatures of the infant brain, time-locked to stimuli events. As a result, ERPs do not necessitate that infants make an overt response. In fact, head movements would seriously distort the ERPs.

In addition, since ERPs more directly reflect cognitive processing, a second advantage of this method is that it does not require infants to have a preference for one type of stimuli over another. A third key advantage of ERPs is that it provides an on-line measure of language processing, with a precision in ms. This allows us to get a better understanding of how quickly infants recognize words, under various circumstances.

ERPs are derived from background EEG signal (electro-encephalography). EEG continuously measures the voltage fluctuations on the scalp's surface (i.e., measures voltage changes between EEG electrodes and a reference electrode on a neutral place, such as on the mastoids). The recorded signal reflects summed post-synaptic electric potentials generated by large collections of aligned pyramidal cells from cortical areas, which fire simultaneously and in synchrony.

Figure 1.2 shows the typical set-up of an infant ERP experiment employed in this dissertation. Before the experiment starts, an infant-size BrainCap with several inserted Ag-AgCl sintered ring electrodes is placed on the child's head. The skin under the electrodes is cleaned with some alcohol and abrasive paste to reduce skin impedance. When the cap is in place, the electrodes are then filled with an electrolyte

Figure 1.2: *On the left, before the experiment can start, a girl is fitted with a cap, and gel is inserted in the ring electrodes. Meanwhile she can play with some toys. On the right, during the experiment, the child sits in an infant seat, facing a screen, while the parent sits to one side.*

paste that conducts the signal from the skull to the electrode (Figure 1.2A). During the experiment, the child is then seated in a child seat, with a parent next to him or her (Figure 1.2B).

In a typical ERP experiment, two (or more) types of stimuli are presented to the participants while their EEG is recorded; for instance, they may hear auditory words that do or do not match a presented picture. The EEG signal is sent to an amplifier, which transports the signal to a computer, so that it can be stored. While the EEG is recorded, certain markers, time-locked to the onset of certain stimuli (e.g., critical words), are also simultaneously sent to the computer, so that it is clear when in the continuous EEG signal a certain stimulus-related activity occurred. There are several steps involved in extracting ERPs from the EEG raw data. I will discuss these steps briefly in turn (but for more detail, see e.g., Luck, 1995). Ultimately, the corresponding ERPs to each type of stimuli are then compared to see if participants can notice a difference between the stimuli types.

With passive electrodes, as is used in this dissertation, the EEG is on-line referenced to one reference electrode (e.g., left mastoid), and then re-referenced to linked mastoids off-line, to avoid any hemispherical biases.

For infant and adult research, the data is then filtered, generally between 0.1 – 30 Hz. although sometimes more restrictive frequency bands are analyzed in infant research, leading to different end products (see, for instance, Weber, Hahne, Friedrich & Friederici, 2004).

The next step in the analysis process is to extract epochs (e.g. 1000 ms) of EEG, time-locked to the onset of certain stimuli, base-lined to a short pre-stimulus window (200 or 150 ms prior to onset), and average these epochs. Averaging is required because the time-locked EEG not only reflects the cognitive processing of this stimulus, but also contains back-ground activity. This background amplitude is larger than the event-related voltage changes, as the comparison between Figure 1.3A and 1.3B shows; consequently, the ERP is hard to detect based on just one epoch. By averaging these epochs one keeps the potential associated with the event, but the back-ground activity is averaged out; hence, the name 'event-related potential' is quite appropriate.

For infants averaging is typically based on 10 epochs (from now on: trials) or more, whereas for adults this is generally at least 30-40 trials. This is because infants have a smaller attention span than adults, resulting in far shorter experiments than is the case in adult research. The longer the experiment lasts, the more infants will fail to finish it. In my experience, 20 minutes is the maximum time period of testing awake infants, and between 10 and 15 minutes is ideal. As a result, however, the signal-to-noise ratio for infants is lower than for adults.

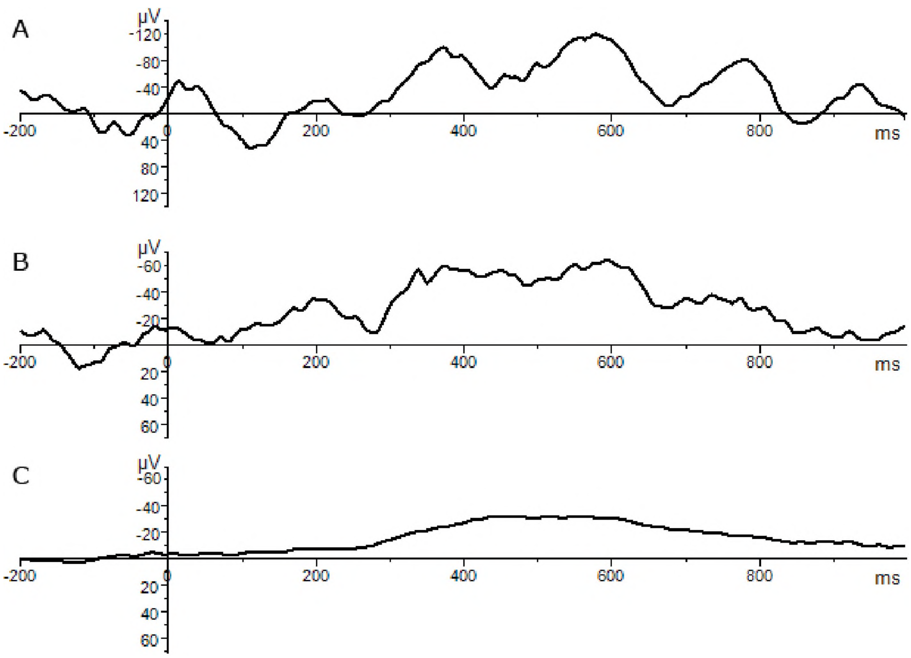

Figure 1.3: *From single trials to grand average waveforms, at a central electrode on the mid-line (Cz). The x-axis plots time, with 0 ms denoting the onset of the stimulus (here, a picture) and the Y-axis plots voltage (negativity plotted upwards). 3A: a single trial from a single subject. 3B: a subject average waveform (here, averaged over 11 single trials). 3C: grand average waveform (here, averaged over 20 subject average waveforms).*

Although experimental time is short, it is important to have about three or four times as many trials per condition as is necessary for averaging. This is because there is a large risk that trials carry artifacts. Including these trials into the average would make a comparison between ERPs less reliable. Therefore a manual trial rejection needs to be carried out first, which checks for eye blinks and movements.

After the trial rejection, the final steps can be carried out: the actual averaging of trials that leads to the subject average waveform (Figure 1.3B). For each condition, all subject average waveforms are then averaged into a grand average: the ERP (Figure 1.3C). ERPs for one or more conditions are then contrasted. Still, one should keep in mind that there is considerable variation between subjects, as becomes clear when one compares the scale and pattern of a subject average waveform (Figure 1.3B) with those of the grand average waveform (Figure 1.3C).

Each ERP consists of a series of positive and negative peaks, called *components*. Components are labeled based on the (relative) polarity (i.e., N for negative, P for positive) and based on the latency. Early components, associated with automatic processes, are generally labeled in serial order (i.e., P1, N1, P2, N2), and later components are labeled by reference to the time in ms (i.e., N400, P600).

Although such components are clearly identifiable in adults, this appears not to be the case for infants, due in part to excess slow wave activity common in infants: Infant EEG is dominated by 4-5 Hz frequencies, whereas adult EEG is dominated by higher frequencies, mainly alpha (8-12 Hz) and beta (12 - 30 Hz). For instance, the N1 and the P2, which are early components present in auditory evoked cortical responses, do not reach adult levels until participants are 14 years or older (Pasman, Rotteveel, Maassen & Visco, 1999). Clearly, the infant brain is still in development, and far from mature: Fontanels are not closed yet, and the number of synapses grows enormously between six and 12 months (Paus, Collins, Evans, Pike & Zijdenbosch, 2001). Together this makes comparison between infant and adult EEG data a difficult process.

The term *effect* is used when the amplitude or latency of a component differs between experimental conditions. An important and well-studied lexico-semantic ERP effect is the N400: it reflects the difficulty at which a word is accessed or integrated into the context (Kutas & Hillyard, 1980; for a review, see Kutas & Federmeier, 2011). For instance, Chapter 2 will show that the N400 is larger for words that are incongruent to a presented picture compared to when the same words are congruent.

There are three main characteristics of an ERP effect: onset, amplitude and distribution. The onset latency of an ERP effect reflects a measure of speed: it indicates how fast the brain picks up differences between stimulus types at a millisecond level. Because language is produced and understood very fast, the high temporal resolution of ERP measurement makes it suitable for language processing research. Early differences between the ERPs, between 0 and 100 ms after onset, generally reflect exogenous differences between stimuli, such as loudness or pitch, whereas differences after 150 ms reflect endogenous differences and are associated with higher cognitive processes. Differences in amplitude indicate changes in the amount of brain activity associated with the processing of these stimuli types.

The distribution of the effect refers to which (cluster of) electrodes the effect is most visible. One disadvantage of ERP research is its low spatial resolution: one cannot infer from the relevant electrodes on the scalp where it is in the brain that the underlying neural signal is generated. This is known as the *inverse problem*. In other words, there is no clear correspondence between the electrodes where the effect arrives and the underlying brain regions. Distribution differences only inform us that different neural generators are involved. However, knowing the distribution of voltages over the head allows comparison with other ERP studies. When several studies report similar ERP effects, consistently with the same distributions, this suggests that the same neural processes are involved across these studies, and therefore the ERPs tap the same brain mechanisms.

Having now explained the method of ERPs and why this provides such a useful insight in how preverbal infants process language, I will now explain what the next five experimental chapters investigated.

Outline of the dissertation

The first experimental chapter (Chapter 2) provides a complete picture of neural signatures corresponding to the necessary steps involved in early word learning: object categorization, word recognition, and word-to-world mappings. It reports an experiment in which nine-month-olds saw pictures of typically early acquired categories (e.g., BALL), then heard a spoken word ("ball"). With the on-line measure of ERPs we can obtain the time-course of object-categorization (i.e., time-locked to the pictures) as well as of word recognition (i.e., time-locked to words). Infants were first familiarized with six picture-word pairings per semantic category. We further manipulated the picture type-token ratio to assess whether this influenced visual categorization and possibly even word recognition. For this purpose, infants either saw the same picture token repeatedly or saw different picture tokens. After each familiarization phase there was a test phase, in which words were either congruent or incongruent with novel pictures of the familiarized categories. Hence, in the test phase infants' ability to make word-to-world mappings is examined. In addition, we assess how ERP effects in this stage are related to infants' present receptive vocabulary. In sum, Chapter 2 provides electrophysiological evidence of the three processes that comprise early word learning, as well as gives evidence of the relevance of word recognition.

In the following experimental chapters we zoom in on infants' ability to recognize words in continuous speech. Speech segmentation skills in infants have been studied with both behavioral and with electrophysiological methods. The first paradigm for studying (cues for) speech segmentation in infants was the behavioral headturn-preference procedure (Jusczyk & Aslin, 1995). In this procedure infants first listen to words in isolation, before their listening time is compared to passages containing these familiarized words versus other passages containing similar but unfamiliarized words. A difference in their listening times implies that infants distinguished between passages, and hence have segmented the individual words from the speech signal.

However, while the HPP provides evidence of the occurrence of word segmentation, it cannot reflect how rapidly this occurred. To address the question of the time course of segmentation, Kooijman (2007; Kooijman, Hagoort & Cutler, 2005) devised an ERP experiment that was an analog of the familiarization-and-test HPP paradigm. She familiarized 10-month-olds with 10 tokens of the same infrequent word in isolation, and then recorded ERPs to these familiarized words, and matched unfamiliar words, in utterances. The infants' brain responses showed a clear recognition response: relative to unfamiliar words, familiar words elicited a negativity around 400 ms after the onset of the word. Since then, this word familiarity effect, tested with a similar familiarization-and-test phase, has also been reported for 12-month-olds from different native languages (French: Goyet, de Schonen & Nazzi, 2010; Männel & Friederici, 2010). In sum, the ERP word familiarity effect provides us with an on-line reflection of word recognition in continuous speech.

Having an on-line measure of ERPs for speech segmentation allows us to further investigate how often and in which context infants should hear an infrequent word before word recognition later in time can be achieved. Chapter 3 and 4 examine the amount and type of exposure needed for 10-month-olds to build up a memory trace sufficient for word recognition. In the study described in Chapter 3, infants first heard a word, either embedded within an utterance or in isolation, and then recognition was assessed by comparing ERPs to this word presented again versus a word they had not heard before. Chapter 4 test whether 10-month-olds can segment words form continuous speech and recognize them again in novel utterances.

Since infants mainly hear multi-word utterances, segmenting words from fluent speech is vital for vocabulary acquisition and later language development (Newman, Bernstein Ratner, Jusczyk, Jusczyk, & Dow, 2006). Chapter 3 and 4 both relate the word familiarity effect for familiarized versus new words in the test phase (as an index for speech segmentation ability) to later language states: to parental ratings on their infants' vocabulary sizes at 12 and at 24 months; and to performance in a preferential-looking study for known words at 16 months, respectively. Chapter 5 and 6 further explore the relationship between the word familiarity effect and future language profiles by follow-ups of the seven- and 10-month-olds from Kooijman (2007). Chapter 5 demonstrates that infants who at seven months showed an ERP effect similar to that of the 10-month-olds had higher language quotients at three years, compared to their peers who showed a different word familiarity effect. Results from Chapters 3, 4, and 5 suggest that with various measures for language development, infants who displayed this word familiarity effect are at a head start, at least up to three years, compared to infants who did not show this ERP effect. Chapter 6 shows that the effect of speech segmentation ability wears off when children start going to school: The relationship is no longer present when the 10-month-olds who participated in the first infant speech segmentation study returned at five years.

Finally, Chapter 7 summarizes results, and provides a general discussion of the main findings, including a comparison of the observed effects in the experimental chapters.

CHAPTER 1: INTRODUCTION

ELECTROPHYSIOLOGICAL EVIDENCE OF EARLY WORD LEARNING

CHAPTER 2

This chapter is a slightly revised version of Junge, C.M.M., Cutler, A., & Hagoort, P. (submitted). Electrophysiological evidence of early word learning.

ABSTRACT

Around their first birthday infants begin to talk, yet they comprehend words long before. This study investigated the event-related potentials (ERP) responses of nine-month-olds on basic level picture-word pairings. After a familiarization phase of six picture-word pairings per semantic category, comprehension for novel exemplars was tested in a picture-word matching paradigm. ERPs time-locked to pictures elicited a modulation of the Negative Central (Nc) component, associated with visual attention and recognition. It was attenuated by category repetition as well as by the type-token ratio of picture context. ERPs time-locked to words in the training phase became more negative with repetition (N300-600), but there was no influence of picture type-token ratio, suggesting that infants have identified the concept of each picture before a word was presented. Results from the test phase provided clear support that infants integrated word meanings with (novel) picture context. Here, infants showed different ERP responses for words that did or did not align with the picture context: a phonological mismatch (N200) and a semantic mismatch (N400). Together, results were informative of visual categorization, word recognition and word-to-world-mappings, all three crucial processes for vocabulary construction.

INTRODUCTION

The ability to learn names for things is an important milestone in language development. Around their first birthday infants start producing their first words. Early word learning, the first 50 productive words, is characterized as a slow and laborious process, with one or two newly produced words per week (e.g., Carey, 1978; Hollich, Hirsh-Pasek & Golinkoff, 2000). Infants' first words typically refer to known exemplars or persons of high relevance to the individual child, such as 'mommy', 'hand' or 'dog' (Clark, 1993; Fenson et al., 1994). Around 18 months, infants' productive vocabulary dramatically increases, a phenomenon also known as the 'vocabulary spurt'. Note, however, that vocabulary spurt is defined by changes in word production, not in word comprehension (Nazzi & Bertoncini, 2003). The average American-English 12-month-old might only produce six words but already understands about 75 words (Bates, Dale & Thal, 1995; Fenson et al., 1994; Golinkoff & Hirsh-Pasek, 2006). Vocabulary construction requires at least three skills in infants: identifying a concept (categorization), identifying a word (recognizing words in a speech stream), and mapping words to objects or events (word-to-world mapping; Waxman & Lidz, 2002).

Although recent research has made good progress in studying infants' abilities on speech and object categorization in isolation (cf. Waxman & Lidz, 2002), little is known about infants' ability to form their first word-to-world mappings, or the interplay between the three processes vital for vocabulary construction. There have been only a few experimental studies that tested infants younger than 12 months on their lexical-semantic knowledge, using the intermodal preferential-looking paradigm (IPL) (Schafer, 2005; Tincoff & Jusczyk, 1999, 2000). In the IPL, infants typically see two objects, while the auditory label matches only one of the two. Their eye movements reveal that infants then generally have a preference for (e.g., look more to) the named versus the not-named referent. Using this paradigm, Tincoff and Jusczyk (1999, 2000) were the first to show that six-month-olds already had some word-world associations. However, whether or not infants were able to recognize certain early words also depends on the experience infants had with these nouns. Schafer (2005) compared infants' ability to map words to novel exemplars of common objects at 12 months when they had or had not received weekly training at home on a set of these objects from nine months on. Only infants with this training experience looked longer at correct exemplars upon naming of a trained category. However, all infants performed at chance when the label belonged to an un-trained category. Clearly, training infants at nine months boosts subsequent comprehension for these words at 12 months. But what happens in the infant brain during familiarization of word-to-world pairings? To address this question, the current study measured event-related brain potentials (ERPs) to explore the neurophysiological changes over the course of typical early word-to-world pairings. We tested nine month-olds, the age at which infants in the Schafer (2005) study started their training.

Little is known about the neural mechanisms of early (spoken) word learning. Studies on visual recognition often report a modulation of the Negative Central (Nc) component (Courchesne, Gaz & Norcia, 1981; Nelson, 1994; cf. de Haan, 2007). It is a fronto-central negative deflection elicited for all types of visual stimuli, but generally largest for novel stimuli, peaking around 400-600 ms for six-to-12-month-olds. Its amplitude is considered to be an index of attention, or of recognition memory. In object categorization studies, the Nc is associated with preference for one category over another (Grossmann, Gliga, Johnson & Mareschal, 2009; Jeschonek, Marinovic, Hoehle, Elsner & Pauen, 2010; Quinn, Westerlund & Nelson, 2006; Quinn, Doran, Reiss & Hoffmann, 2010). Studies on auditory word processing in infants, on the other hand, show that ERPs for familiar words are more negative than for unfamiliar words (N200-500). This is the case for known versus unknown single words (e.g., Thierry, Vihman & Roberts, 2003) as well as for familiarized versus unfamiliarized low-frequency words in continuous speech (e.g., Kooijman, Hagoort & Cutler, 2005; Goyet, de Schonen & Nazzi, 2005).

In a pictorial context, words that matched the picture elicited a smaller N400 than words that did not match the picture (e.g., Desroches, Newman & Joanisse, 2009; Friedrich & Friederici, 2004). The N400, a negative component peaking around 400 ms after stimulus onset at posterior electrodes, is a reliable index of lexical-semantic processing. It reflects the difficulty of accessing and integrating a word into its current context (Kutas & Hillyard, 1980; cf. Kutas & Federmeier, 2011). This component has been observed in adults as well as in older infants. A few studies used the picture-word matching paradigm to test lexical-semantic processing in infants of 12 months and older, with different results.

Friedrich & Friederici (2004, 2005a, 2005b) tested 12-, 14-, and 19-month-old German infants as well as adults. All infants showed an early frontal negativity for congruous relative to incongruous words ("phonological-lexical priming effect"). Adults showed a long-lasting N400, which was also present but delayed for infants up to 14 months. At 12 months, only those infants who produced more than four words showed the N400 effect (Friedrich & Friederici, 2010). These results imply that the infant N400 neural mechanisms are still in development. Moreover, they point to a link between the presence of the N400 and infants' word learning abilities. The reason why some infants' brain responses do not yet distinguish between correct and incorrect words could be due to a reduced ability to pair correct words with pictures successfully.

Mills & colleagues (cf. Mills, Conboy & Paton, 2005) also used the picture-word matching paradigm to test several ages, but their results suggest that the neural systems involved in semantic integration were comparable across development. Infants before the 'vocabulary spurt' (e.g., 13-month-olds) showed an N400 with a similar early onset as was seen in 20-month-olds, three-year-olds and adults. Moreover, the 'phonological-lexical priming effect' was not observed in any age group. Clearly, results from the picture-word matching design for infants are not convergent between studies. Besides the factor age, there are several differences in the experimental set-ups between the two lines of studies that each could have attributed to the different results. For instance, the ratio of 'match' versus 'mismatch' words is balanced in the studies carried out by Mills and colleagues, whereas in the studies carried out by Friederici and Friedrich, infants encounter three times as many 'mismatches' than 'matches'. Moreover, Mills made sure that not only did the infants understood the words tested (as rated by their parents) but also included only those trials where infants were fixating the screen. This was not the case by Friedrich and Friederici: They used a general set of typical early words. Nevertheless, whatever other possible reasons there might be that can explain these discrepancies, both type of studies provide evidence that in a pictorial context, infants process incongruous words differently than congruous words.

To date, there have been two ERP studies that examined novel word-to-world mappings in older infants (14-month-olds: Friedrich & Friederici, 2008; 20-month-olds: Torkildsen et al., 2008, 2009). Here, infants were first familiarized with pairings between pictures of novel objects and novel words. ERPs time-locked to the onset of pictures showed a modulation of the Nc, which was decreased with repetition. ERPs time-locked to the onset of words revealed that the more often words were presented, the larger the N200-400/500. This latter effect only occurred when words were consistently paired with the same category and not with random pictures, which implied that infants integrated the novel words with pictures. Word comprehension of trained pairings was subsequently tested in a picture-word matching paradigm. Both studies reported an N400 when the novel word did not match with the novel object anymore.

However, novel word learning differs from early word learning in that infants learn novel labels for objects they do not have any prior experience with. Moreover, infants are often tested at an age at which they already have a small lexicon (i.e., 14 months or older). Having some understanding of words could boost subsequent learning (e.g., "naming insight", McShane 1980; but see McMurray, 2007; Smith, 1999). Together, these considerations imply that learning names for novel objects may not be identical to learning names for known objects.

In the current study nine-month-olds were presented with ten training-test blocks. Each block always started by familiarizing the infants with two different words that are typically acquired very early (e.g., 'cat'- 'ball'). Each training phase showed six picture-word pairings of one semantic category (e.g. 'cat'), followed by six pairings of another category (e.g. 'ball'). In the test phase we examined infants' ability to make word-to-world mappings by presenting new examplars of the trained categories twice, once with the correct label ('match') and once with that of the contrasted category ('mismatch'). See Figure 2.1 for an example of a training-test block for the example 'ball' -'cat'.

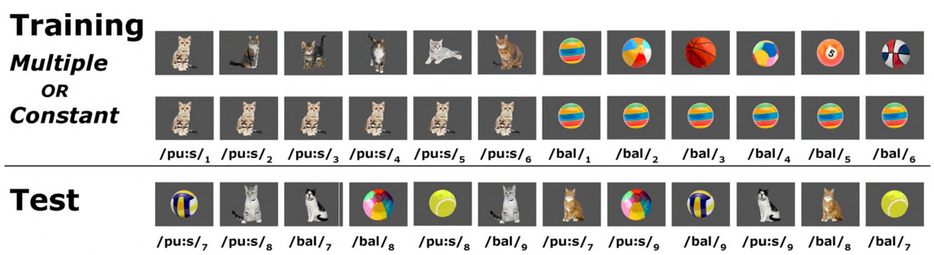

Figure 2.1: *An example of the training and test phase for the block 'ball' -'cat'. Half of the infants saw this training phase with constant pairings (same picture six times); others saw this phase with multiple pairings: six different cats and six different balls. Each time a picture was presented, a novel token of a matching word was presented 1 s later, with the picture still on the screen. The test phase always consisted of three novel picture and word exemplars per category, each presented once in a congruous and once in an incongruous pairing.*

We further manipulated the picture context of the training phase. Behavioral research on visual categorization showed that at test infants preferred an unfamiliarized category more (i.e., they are more habituated to the familiarized category), when familiarized with different exemplars than when presented with identical exemplars (e.g., Reznick & Kagan, 1984). Therefore, to test the influence of visual categorization on subsequent word comprehension, we manipulated the type-token ratio of categories. Half of the training blocks consisted of constant pairings (the same picture per category presented six times), and the other blocks consisted of multiple pairings (six different pictures per category).

We measured ERPs time-locked to pictures as well as to words, which were presented one second after onset of picture. For category processing, we predicted that the Nc is reduced for the second half of the training phase (repetition effect). The type of pairings should also influence the Nc: The amplitude should be larger for different exemplars than for repetitions of the same exemplars. For early word familiarization we predict an N200-500 for the second half of a training phase. The picture context could influence this word familiarization effect. If infants had more difficulty identifying the category when different pictures of the same category were presented than when the same picture was repeatedly presented, then the N200-500 could be decreased or delayed. However, if infants had identified the category by the time the word was presented, even when different exemplars were presented, then training context should not influence the amplitude or onset of the word familiarity effect (N200-500).

After each training block we tested word comprehension of these two categories (e.g. 'ball' and 'cat'). Regardless of training context, the test phase always consisted of novel exemplars of trained categories, whose names were once congruous and once incongruous (from the contrasting category) to this novel exemplar. We predicted that infants would show evidence of an incongruency effect from word onset on, indicating that they can attach labels to novel exemplars after training. We further predicted that infants would find it easier to recognize novel tokens as belonging to a certain type when multiple tokens of this category had previously been presented in the training phase. This would then be reflected in a larger semantic incongruency effect for words following novel tokens of a category when trained with multiple pairings, than when trained with constant pairings. If, however, type of picture-word pairings does not affect (the latency or size of) the ERP effect of word familiarity in the training phase, then we would similarly expect it not to affect semantic congruity effects in the test phase. Together, the results from the training and test phase provide an insight into the neural mechanisms of early word learning.

METHOD

Participants

Twenty nine-month-old infants (nine female) participated. Their mean age was 282 days (SD = 6.1 days). An additional 11 infants were tested, but excluded due to inattentiveness (n = 2); refusal to wear the cap (n = 1); computer problems (n = 1); or retaining too few artifact-free trials (n = 7). All subjects were healthy, full-term infants from monolingual Dutch families with no history of neurological or language impairments. The majority had college-educated parents. Infants were recruited from the Nijmegen Baby Research Center Database. Parents signed informed consent forms, and received 20 euro and a photograph of their child taken after the experiment in appreciation of their participation.

Materials

Twenty easily depicted basic-level nouns were selected from the Dutch version of the MacArthur-Bates Communicative Development Inventory (CDI: Fenson et al., 1993; N-CDI: Zink & Lejaegere, 2001), based on likelihood of understanding the word at 12 months and of being visually familiar with its referent at nine months. We selected words based on 41 N-CDIs for 12-month-olds (21 boys; mean age 366 days, SD = 10.1 days) collected previously in the Nijmegen Baby Research Center. The mean percentage of 12-month-olds understanding the 20 selected words was 47.6% (SD = 11.7%). The twenty words came from the following six semantic domains: animate

(4); clothing (3); body parts (3); furniture (3); food (3); toys (2) and vehicles (2). See Table 2.1 for an overview of the words.

For each word, ten auditory tokens were recorded by a female native speaker of Dutch in a sound-proof booth in a lively child-directed manner, and digitized at a sampling rate of 44.1 kHz. The mean duration of words was 621 ms (SD = 103 ms; mean SD per word = 45 ms).

Per category, there were 10 different color stock photographs (modified with Adobe Photoshop). The photographs were roughly of the same size and appeared in isolation on a dark-grey background. See Appendix 1A for all visual stimuli.

Table 2.1: The twenty nouns used in the experiment, split by block. *Per block, two words were contrasted; for instance, 'cat' and 'ball' for the first block. For each word, its phonetic transcription in Dutch, category membership (domain) and the mean average ratings of visual familiarity and likelihood word comprehension are reported. Parents rated visual familiarity as how often their child would see each semantic category in real life or in books on a scale from 0 (never)- 5 (every day), with 3 as 'once a week'. They rated word comprehension on a scale from 1 (not) - 5 (well), with 3 as 'maybe'.*

Block	Semantic Category A	Phonetic Transcription	Domain	Visual Rating	Word Rating	Semantic Category B	Phonetic Transcription	Domain	Visual Rating	Word Rating
1	**cat**	[pu:s]	animate	2.3	2.6	**ball**	[bɑl]	toy	4.5	3.7
2	**mouth**	[mɔnt]	body part	4.6	3.1	**chair**	[stu:l]	furniture	4.6	3.1
3	**car**	[ɔuto:]	vehicle	4.6	3.4	**banana**	[bɑna:n]	food	3.2	2.9
4	**foot**	[vu:t]	body part	4.6	3.4	**bed**	[bɛt]	furniture	5.0	3.9
5	**dog**	[ɦɔnt]	animate	2.2	3.2	**book**	[bu:k]	toy	4.5	3.7
6	**sock**	[sɔk]	clothing	4.3	3.0	**bottle**	[flɛs]/[flɛsjə]	food	4.9	4.3
7	**baby**	[be:bi:]	animate	3.6	3.2	**cookie**	[ku:kje]	food	2.8	2.8
8	**coat**	[jɑs]	clothing	4.4	2.9	**bicycle**	[fi:ts]	vehicle	3.3	2.7
9	**bath**	[bɑt]	furniture	3.8	3.6	**cow**	[ku:]	animate	2.0	2.0
10	**shoe**	[sxu:n]	clothing	4.0	2.8	**hand**	[ɦɑnt]	body part	5.0	2.6

Procedure

The experiment comprised 240 picture-word trials. Pictures stayed on the screen for 2200 ms, with the word presented 1000 ms from picture onset. The inter-trial interval was 1000 ms. There were ten training-and-test blocks, with each block contrasting two semantic categories. These two categories always came from different semantic domains, e.g. 'cat' (animal) versus 'ball' (toys). Moreover, the labels of the two contrasted categories did not share any overlap in onset or vowels (see Table 2.1). A block consisted of 12 trials in the training phase, followed by 12 trials in the test phase. Each training phase started with six picture-word trials of one category, followed by six picture-word trials of the second category. The type of training (constant versus multiple pairings) varied as a within-subjects variable but was kept constant per block. Half of the blocks consisted of constant pairings; that is, the same picture was presented six times, each time with a different token of the congruent word. The other five blocks consisted of multiple pairings: six different exemplars of a category, each paired with a different auditory token of the correct verbal label. There were no more than two blocks with the same type of training in a row.

The test phase was alike for each training type: There were three novel pictures and words per category that had not been presented in the training phase. Each picture and each word were presented twice: once in the congruent condition and once in the incongruent condition. In this way congruency effects could not be due to physical differences between pictures or between words. Presentations of the six congruous and six incongruous picture-word pairs were quasi-randomized so that the same token never appeared consecutively, and with no more than two congruous or incongruous trials in a row.

To avoid item-specific and order effects, we constructed four presentation lists, counter-balancing type of pairing per block, order of blocks, and order of categories within a block. Each list was randomized, so that for some infants certain items were presented in the training phase that were part of the test phase for others with the same list. Each list was presented to five infants.

During the experiment the infant sat in a child seat in a sound-proof booth. Visual stimuli were presented on a 19 inch computer screen with a 60Hz refresh rate and a 1024 x 768 pixel resolution, situated 1m in front of the child. Words were presented at an intensity of 65 dB through two loudspeakers placed 1.5m in front of the child. Infants were video-monitored to control whether they processed the visual information. Attention-grabbers (short video clips of cartoons, e.g. a moving merry-go-round or a duck going to bed) were played after every two blocks and whenever infants were losing interest. A parent sat next to the child, listening to masking music through closed-ear headphones. Breaks were taken when necessary. The experiment lasted 14 minutes, and a whole session about an hour.

After the experiment, parents filled in the N-CDI for infants. Infants produced between zero and two words (mean 0.15, SD 0.49) from the N-CDI, and understood on average 53 words and utterances (SD 41.7). Parents also filled in two questionnaires designed for this experiment. These measured visual familiarity and word comprehension for each of the twenty categories used in the experiment, with a higher rating indicative of a better understanding of a category. Average visual familiarity, rated on a scale from 0-5, was 3.9 (SD 0.48), corresponding to seeing items at least once a week. Average word comprehension, on a scale from 1-5, was 3.1 (SD 0.56), corresponding to 'maybe'. There were no correlations between subject mean ratings and vocabulary scores (Pearson's $r = +.02 - +.37$; $p > .11$). When mean ratings per word were calculated (averaged over infants), we observed a significant positive correlation between visual and word familiarity ratings, indicating that the more often objects were seen, the better their labels were understood ($r = +.61$, $p = .005$).

EEG Recordings and Pre-processing

EEG was recorded with a sampling rate of 500 Hz, using an infant-size BrainCap with 24 inserted Ag/AgCl sintered ring electrodes, placed according to the extended 10-20 system (F7, F3,Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8, Oz). Vertical eye movements and blinks were monitored via a supra- to sub-orbital bipolar montage and horizontal eye movements via a right-to-left canthal bipolar montage. Electrodes were referenced online to the left mastoid and re-referenced 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 signal was filtered with an on-line filter of 0.01-200 Hz and an off-line filter of 0.1 - 30 Hz. Trials were time-locked to the onset of pictures as well as to the onset of words. Based on video recordings we rejected trials (for both words and pictures) when infants were not looking at the screen[1]. Individual trials with a baseline of 200 ms were furthermore screened for artifact from 200 ms before to 800 ms after target onset. They were automatically rejected when amplitudes exceeded +/- 200 µV, and manually rejected when we detected clear correlations with the eye channels or activity in the right mastoid during recording. The electrode Oz was excluded from analysis due to excessive artifact. The persons coding the video-recordings and performing the manual artifact rejection of the remaining trials were blind to the conditions of the experiment. For each infant, we calculated average waveforms per condition, with a minimum of ten artifact-free trials per condition. Infants attributed on average 15.7 artifact-free trials per condition (SD 3.0).

Statistical Analyses

We report both behavioral and electrophysiological results. For behavioral results we analyzed the number of trials when infants looked away. For electrophysiological results, we calculated mean amplitudes for selected time windows per condition for each of the 20 lateral electrodes. Time windows were selected based on visual inspection of the waveforms. For all ANOVA tests, we used the Huynh-Feldt epsilon correction and we report here original degrees of freedom, adjusted p-values, and adjusted effect sizes (partial eta-squared: η^2). To test topographic distribution of the relevant effects, we added the factors anterior/posterior (2), hemisphere (2: left, right),

[1] For four infants we did not have video recordings. Here, we used information from additional attention-grabbers as a measure of inattentiveness, and rejected the two trials prior to the onset of these attention-grabbers.

and electrode (5) to the ANOVAs. This created four quadrants of the brain: left frontal (F7, F3, FC1, FC3, C3); right frontal (F8, F4, FC2, FC6, C4); left posterior (T7, CP5, CP1, P7, P3), and right posterior (T8, CP6, CP2, P8, P4).

To assess the effect of repetition in the training phase, we compared results for the first (first three trials) versus the second part of the training phase (second three trials), with type of pairing (constant versus multiple pairing) as a within-subjects factor. For the training phase, we analyzed ERP repetition (2) and type of pairing (2) effects separately for visual processing (time-locked to the onset of picture), and for word processing (time-locked to the onset of the word).

For the test phase, we compared results for congruous versus incongruous words, with again type of pairing (in training phase) as a within-subjects factor. We only analyzed selected time windows time-locked to the word. As all words and pictures in the test phase were presented once in the congruous and once in the incongruous condition, a congruity effect could therefore only be due to the pairing between pictures and words.

RESULTS

Behavioral results

First we calculated the number of trials that infants were not looking at the screen from the first and second part of the training phase, separately for the two types of pairings (i.e., constant and multiple pairings). The maximum number of picture-word trials that infants could observe per condition was 30. For the first versus second part of the training phase, infants did not look at the screen for 2.35 (SD 2.98) and 3.35 (SD 3.07) trials for blocks with constant pairings, and 2.10 (SD 2.85) and 2.70 (SD 3.08) for blocks with multiple pairings. There is a marginal effect of repetition ($F_{1,19}$= 3.67, p =.070, η^2 =.16), indicating that infants were more likely to lose interest in the second block of training. There is no main effect or interaction with type of pairing ($F_{1,19}$<1.64, p>.20; also see Supporting Table 1a, Appendix 3A).

For congruous versus incongruous trials in the test phase, infants did not look at the screen for 4.10 (SD 4.39) and 3.95 (SD 4.14) trials for the constant pairings, and 3.95 trials (SD 3.89) and 3.70 (SD 4.09) for the multiple pairings. There are no significant effects for the test phase ($F_{1,19}$ < 1; cf. Supporting Table 1b, Appendix 3A). Infants were, however, significantly more likely to divert their gaze in the test phase than in the training phase ($F_{1,19}$= 6.15, p =.023, η^2 =.24). The type of pairings they received in the training phase did not influence this difference ($F_{1,19}$ < 1; see Supporting Table 1c, Appendix 3A).

Electrophysiological results: Training phase from picture onset

Figure 2.2 shows the grand average waveforms time-locked to the onset of pictures, with a 200 ms baseline, up to the onset of the word at 1000 ms, for the four conditions in the training phase (first versus second half of the training phase, for constant and multiple pairings, respectively). All conditions elicited a large broadly-distributed negative wave from 300 ms onwards, which is typical for visual processing (de Haan, 2007). Only on lateral parietal electrodes (P7, P8) do we observe an opposite polarity. Based on visual inspection, we chose the 300-750 ms interval for analysis, which is a standard interval for the Nc-component (de Haan, 2007). Statistical analyses show that there are main effects of repetition ($F_{1,19}$= 12.2, p =.002, η^2=.40) and of pairing type ($F_{1,19}$ = 8.21, p =.010, η^2 = .30), but no interaction between the two ($F_{1,19}$ = 1.76, p =.20, η^2 =.09). (See also Supporting Table 2 in Appendix 3A). First, the Nc is reduced for the second part compared to the first part of the training phase, regardless of type of pairing. Second, the Nc is more reduced for constant than for multiple pairings in each of the parts of the training phase. In addition, both repetition and type of pairing have an interaction with posterior/anterior distribution ($F_{1,19}$ = 12.0, p =.003, η^2 =.39; $F_{1,19}$ = 5.08, p =.036, η^2 =.21, respectively), indicating that both the repetition and the type of pairing effects are largest over anterior electrodes.

Electrophysiological results: Training phase from word onset

We further examined ERPs from word onset. Figure 2.3 shows the grand average waveforms time-locked to the onset of the word, again for the four conditions in the training phase (first versus second half of the training phase, for constant and multiple pairings, respectively). Whereas we observed a large negative wave peaking around 600 ms for picture processing, we see a large positive wave peaking around 400 ms on anterior electrodes for auditory word processing. Other studies of auditory single word processing have also reported a large positive wave (e.g., Kooijman et al., 2005; Sheehan & Mills, 2008). This makes it more likely that this component is reflective of word processing rather than being a late component of picture processing. As predicted, this positive wave is reduced by repetition.

Visual inspection shows that the point of time where the ERPs for the first and second block diverge is around 250-300 ms, and that this is the same for both constant and multiple pairings. Indeed, statistical analyses for the 300-600 ms interval show a main effect of repetition ($F_{1,19}$ = 36.4, p <.001, η^2 =.66), but no main effect of or interaction with type of pairing ($F_{1,19}$ =.23, p =.64, η^2 =.01; $F_{1,19}$ = 1.48, p =.24, η^2 =.07, respectively), or any other interactions involving distribution and type of pairing. The only significant interaction is between repetition and anterior/posterior ($F_{1,19}$ = 42.1, p <.001, η^2 =.69): The effect of repetition is largest over anterior electrodes. (See also Supporting Table 3a from Appendix 3A).

Since there is no influence of type of pairing on word repetition, we collapsed over trials with multiple and constant pairings. To investigate the effect of word recognition in a graded manner, we then compared ERPs for word onset in the training phase for picture-word combinations 1-2 and 3-4 and 5-6. There is again a main effect of word repetition ($F_{2,38}$ = 10.9, p <.001, η^2 =.37), and an interaction of

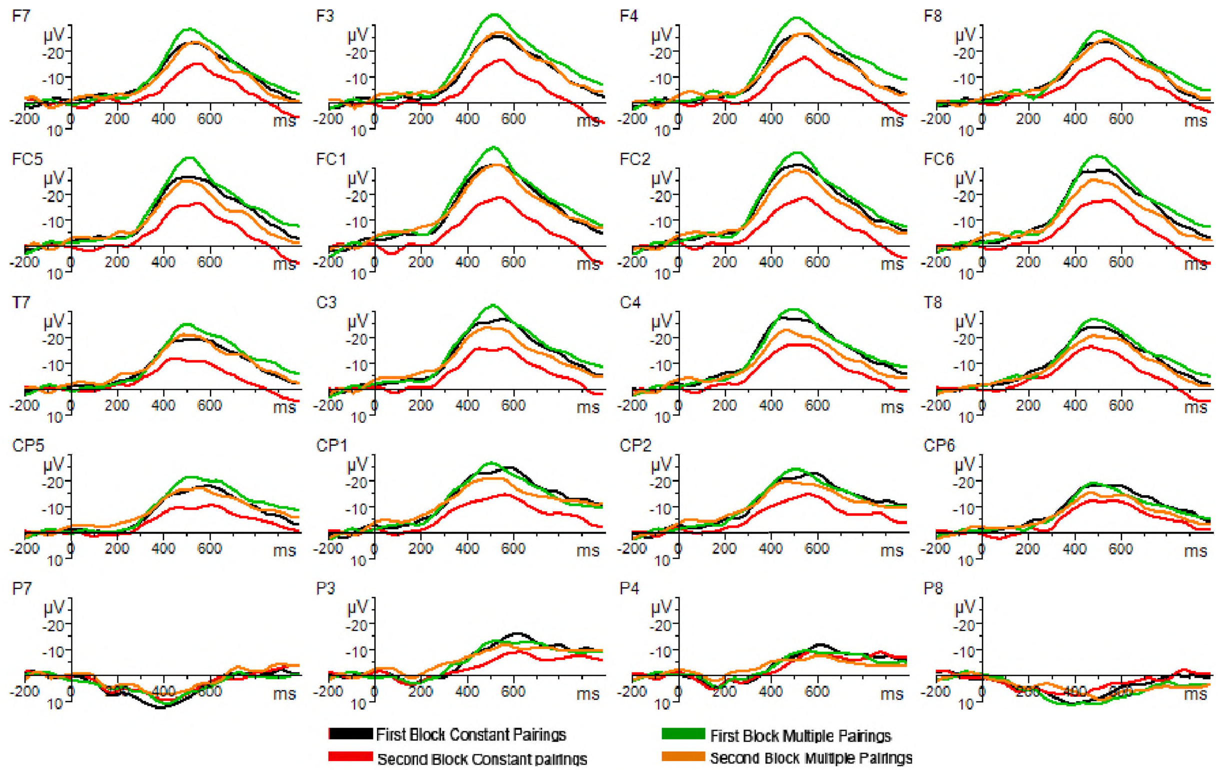

Figure 2.2 : *Grand average waveforms, time-locked to picture onset, for the first and second block of the training phase, for the constant and multiple pairings. (In this and all following ERP figures, electrodes are arrayed for most anterior (top) to most posterior (bottom), and from left to right as they were positioned on the scalp; negativity is plotted upwards; an 8 Hz low-pass filter has been applied for illustrative purposes*

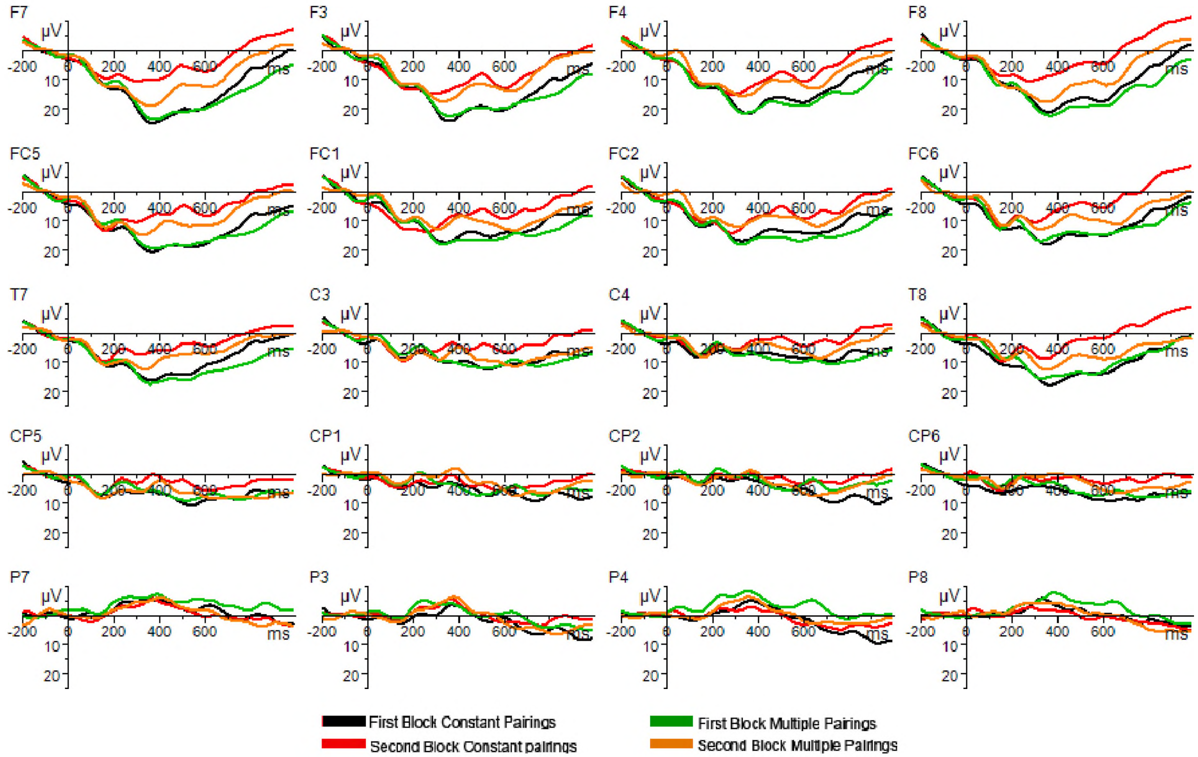

Figure 2.3 *Grand average waveforms, time-locked to word onset, for the first and second block of the training phase, for the constant and multiple pairings.*

word repetition by anterior/posterior ($F_{2,38}$ = 14.4, p <.001, η^2 =.43; see also Supporting Table 3b from Appendix 3A). Figure 2.4 demonstrates this: The more often a word is presented, the more reduced the ERP becomes. The graded familiarity effect is more pronounced over anterior electrodes.

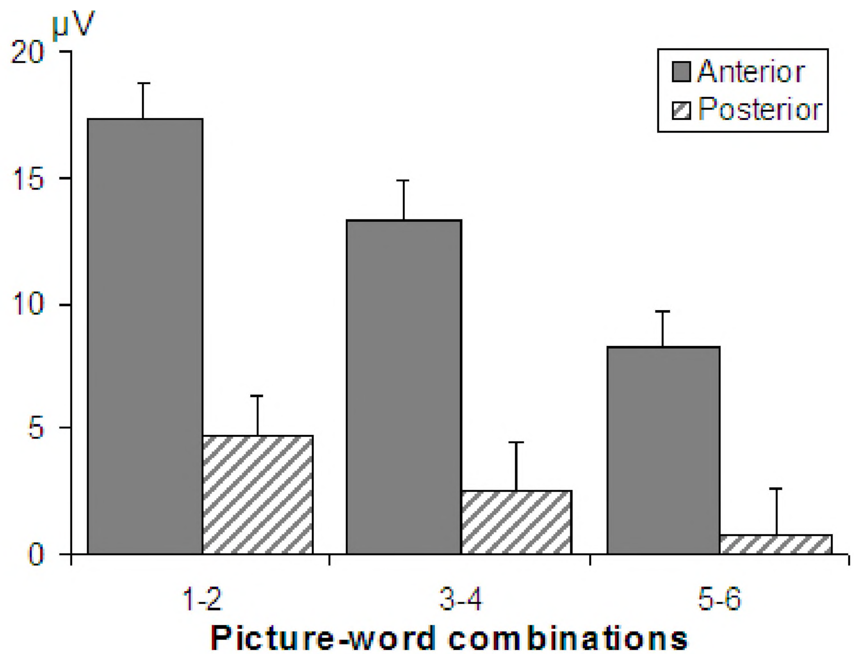

Figure 2.4: *The ERP for word repetition is graded and becomes more negative the more often a word is presented. ERPs are here time-locked to the onset of the word, averaged separately for anterior (average of F3, F4, F7, F8, FC1, FC2, FC5, FC6, C3 and C4) and for posterior (average of T7, T8, CP1, CP2, CP5, CP6, P3, P4, P7, P8) electrodes, for the time window 300 – 600 ms. Error bars reflect one standard error of the mean.*

Electrophysiological results: Test phase from word onset

Figure 2.5 shows the grand average waveforms time-locked to the onset of the word, for the congruous and incongruous conditions, split by type of pairings (See

Appendix 2A, for all 20 lateral scalp electrodes). As in the training phase, we observe a large positive wave which we associate with auditory word processing. There are two time windows where the ERPs for congruous words diverge from that of incongruous words.

From 200-300 ms (N2 window), incongruous words elicited a larger negative going deflection than congruous words, which is more pronounced over anterior electrodes. There is a main effect of congruity ($F_{1,19}$ = 5.64, p =.028, η^2 =.23), but no main effect of or interaction with type of pairing ($F_{1,19}$ < 1; p >.5), or any interactions with quadrants (See also Appendix 3A, supporting Table 4a).

From 300-400 ms the waveforms converge. The effect of congruity is then no longer significant ($F_{1,19}$ = 1.63, p = .22, η^2 =.18; cf. Supporting Table 4b in Appendix 3A). The ERPs for congruous versus incongruous words diverge again from 400-600 ms, for constant as well as for multiple pairings. For this last time window the ERPs for incongruous words again show a more negative-going deflection than the ERPs for congruous words ($F_{1,19}$ = 7.52, p =.013, η^2 =.28), but there are no interactions or main effects with type of pairing or with quadrant factors ($F_{1,19}$ < 2.45, p>.13; see also Appendix 3A, supporting Table 3c). Because there is no interaction with pairing type, we could once more collapse over type of pairings. Here, the average N400 effect over posterior electrodes is significantly related to vocabulary size at 9 months (R = -.48, p =.034). Figure 2.6 illustrates this: The larger the negativity over parietal electrodes, the more words the infant is reported to comprehend. The size of the N400 effect, on the other hand, did neither correlate with the parental ratings on the 20 test items concerning visual familiarity nor with those on likelihood of word comprehension (p ≥ .18, See also Appendix 3A, Supporting Table 5). However, the parental ratings did not correlate with any ERP measure (See further Appendix 3A, Supporting Table 5 for a full into-depth correlational analysis of the results).

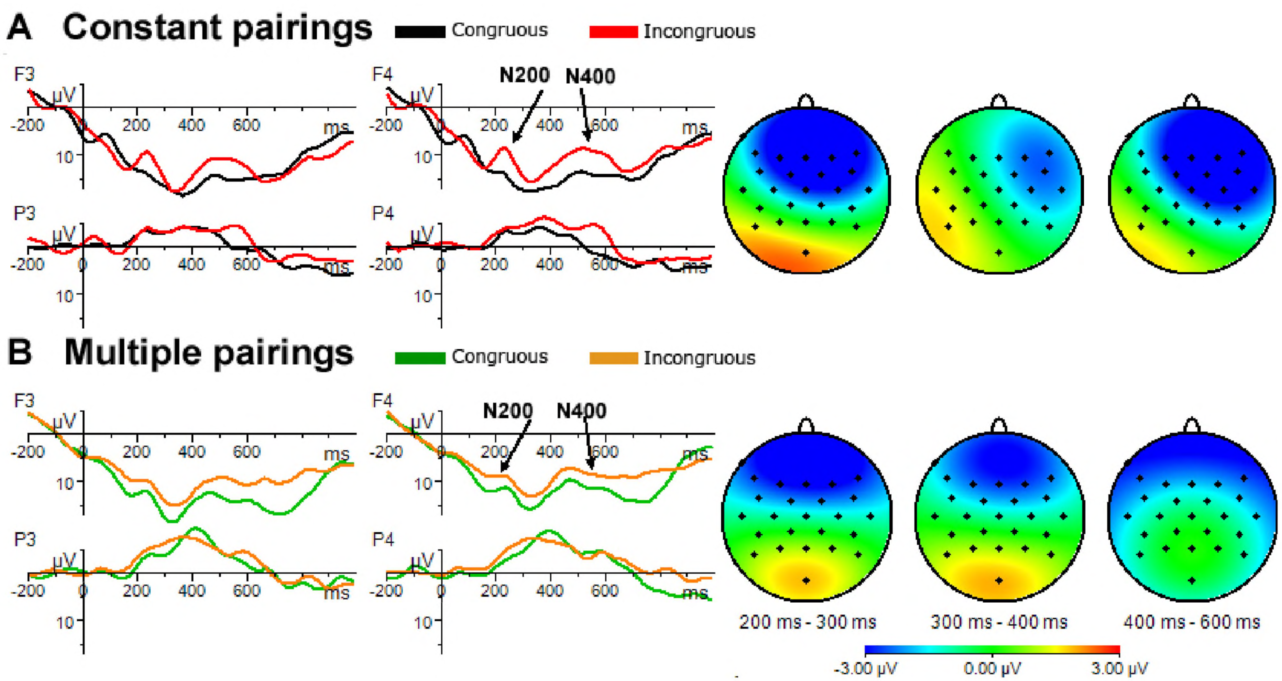

Figure 2.5: *Grand average waveforms for congruous and incongruous words for a left and right frontal electrode (F3/4) and a left and right posterior (P3/P4) electrode; with distribution plots (incongruous - congruous) of the examined time windows on the right; negativity is plotted upwards; 0 ms indicates word onset. Figure 5A: for constant pairings, Figure 5B: for multiple pairings, respectively.*

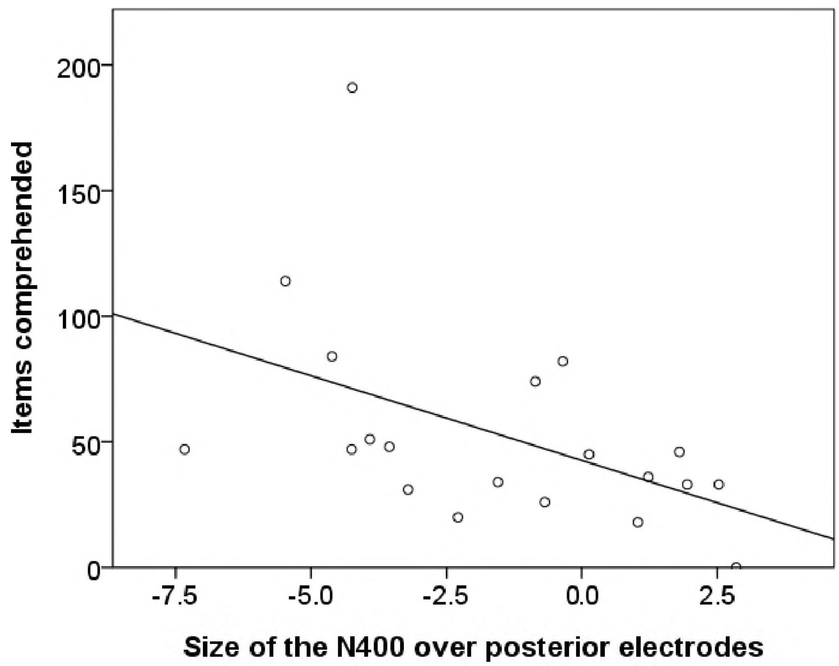

Figure 2.6: *A significant correlation between the size of the Congruency effect (incongruous - congruous) over posterior electrodes at the X-axis, and number of items (words and typical utterances) understood at nine months, at the Y-axis. This is still significant when excluding the outlier at (-4,193; 187): r = -.51, p = 028.*

DISCUSSION

The primary goal of this study was to obtain electrophysiological evidence of on-line early word learning in nine-month-old children. After a familiarization phase of six picture-word pairings per category, comprehension for novel exemplars was measured in a picture-word matching paradigm. Results gave evidence of visual categorization, word recognition and word-to-world-mappings, all three crucial processes for vocabulary construction. During the training phase, infants displayed a suppressed Nc effect for picture repetitions, which was also modulated by the type-token ratio of picture context. ERPs time-locked to words also showed a Word Familiarity effect, which was not affected by type of pairings. Results from the test phase provide clear support that infants integrated word meanings with (novel) picture context. Here, we observed an N200 and an N400 effect for words that are incongruous with the pictures. In the following sections we discuss these findings separately.

The Nc effect for picture processing

The Nc in this study was attenuated by repetition as well as by the type-token ratio of pictures. Traditionally, the amplitude of the Nc is considered to be an index of attention allocation (Nelson, 1994): Its amplitude can be influenced by novelty or by repetition priming (e.g., Quinn et al., 2006; Quinn et al., 2010; Wiebe et al, 2006), as well as by saliency (i.e., larger for mother's face versus stranger's face; de Haan & Nelson, 1997). Behavioral measures in this study also revealed that infants progressively look less at exemplars of one category over time, which indicates that they habituated to the trained category. Hence, the behavioral results further provide evidence that infants were sensitive to repetition, suggesting that it is attention that modulated the Nc here. On the other hand, there was no behavioral evidence that infants were sensitive to the type-token ratio of pictures, although the Nc was also influenced by the type of pairings received in the training phase. Whether it was attention, recognition, or an interplay between the two that drove the modulation of the Nc, its existence implies that the infants have encoded the pictures.

Other visual categorization studies with a familiarization phase of just one category, however, reported a modulation of the Nc only for the test phase, when it was increased for a novel category compared to the familiarized category (Grossmann et al., 2009; Quinn et al., 2006, 2010). Repetition was in that case studied by contrasting an ERP average of the first half (18-20 tokens) versus the second half of the familiarization phase, whereas we compared the first three versus the last three tokens of a category. Consequently, the lack of a differentiation of the Nc for the familiarization phase in these studies could have been masked by averaging over too many successive repetitions of the same category. This is in line with recent research showing that the Nc is sensitive to saliency or novelty, which can change over the course of an experiment (Stets & Reid, in press).

In sum, our results show that when infants are familiarized with only six tokens of a category, both repetition and type-token ratio of exemplars influence a mid-latency component associated with attention and recognition. The timing of this effect suggests that infants have identified the picture before the presentation of the word.

The word familiarity effect

In a pictorial context, ERPs for words in the second half became more negative than in the first half of the training phase (N300-600). A similar negative middle-latency familiarity effect (i.e., N200-500) has been observed in two types of auditory word processing studies in infants: both for words rated by parents as known versus unknown to their child (e.g., Mills, Coffey-Corina & Neville, 1993; 1997; Thierry et al., 2003), as well as for unknown but familiarized words versus unfamiliarized words (e.g., Kooijman et al., 2005). Although Mills and colleagues showed that the N200-500 for 20-month-olds is related to word meaning and not to word familiarity (Mills, Plunkett, Prat & Schafer, 2005), Junge and colleagues hypothesized that for younger infants the same recognition mechanism is sensitive to word form repetition, so that meanings of words can be learned (Junge, Hagoort, Kooijman, & Cutler, 2010; Junge, Kooijman, Hagoort & Cutler, under review). Results from the present study confirm the suggestion that the same mechanism is involved in recognizing word familiarity as well as word meaning. The word familiarity effect in the current study was measured by repetitions for early typical words that the majority of 12-month-olds would understand. Infants in this study comprehended the words to some extent (i.e. average parental rating was 'possibly understood'), yet it was repetition of these items that elicited the word familiarity effect. Moreover, this effect was graded: The more often the item was repeated, the more negative the corresponding ERP became. It had a similar polarity and distribution as observed in auditory familiarization studies, although its latency was delayed by 100 ms (i.e. N300-600 observed in a cross-modal context versus N200-500 in an auditory context). This delay could be the consequence of having words presented in the context of a picture.

The finding that the type-token ratio of pictures did not influence the word familiarity effect suggests that infants have encoded the picture before word onset. The similarities between the word Familiarity effect in this and other auditory studies suggest that infants recognize early typical words in a similar way with or without supporting context.

Semantic congruity effects

There are two accounts of how infants build up their first word-to-world pairings. According to the 'Emergentist Coalition Model' (Hollich et al., 2000), infants start building a vocabulary on the foundation of three principles: reference, i.e., the knowledge that words symbolize concepts; extendibility, i.e., the knowledge that words map to more items than only the original referent; and object scope, i.e., the knowledge that words map to whole objects. Bloom (1993, 2000), on the other hand, claimed that infants' first words are initially differently represented than at a later age: At first, infants co-register the context in which words are learned, making context a crucial correlate to comprehend words. Only at a later age can they recognize words in a more abstract way, e.g. across different contexts. These two models predict different outcomes for the present study. The former model predicts that nine-month-olds are able to attach labels to never-before-seen tokens, whereas the latter predicts they cannot.

Our results support the Emergentist Coalition Model. In the present study infants always saw three exemplars per category that were not presented in the training phase. We found two semantic congruity effects here when labels did not fit the picture context. This indicates that infants as young as nine months were not only able to recognize novel tokens as belonging to the same types, but were also able to attach the correct labels to them. This implies that these infants already have the principles of reference as well as of extendibility. In other words, these infants show signs of lexical-semantic processing skill. This was both the case when, prior to test, they were familiarized with one or with six different visual tokens of a category. Furthermore, these congruity effects also validate our assumption that the Word Familiarity effect in the training phase was not due to just auditory repetition, but reflects word recognition in the context of visual information. Notice, however, that in the training phase picture-word pairs of a category were always presented consecutively. It will be interesting to see in future experiments whether a training phase with randomized presentations of the two categories (which is closer to how infants learn words in real life) will also elicit the same semantic congruity effects that we have observed for the test phase in this experiment.

The first semantic congruity effect was observed in the time window 200-300 ms after word onset. A semantic congruity effect starting at 200 ms has also been observed in other infant studies using the match-mismatch paradigm; however, it is often considered to be part of the N400, i.e. N200-600 (Mills et al., 2005; Torkildsen et al., 2008). Indeed, in adult literature, the onset of the N400 is frequently observed from 200 to 600 ms, during which ERPs for match or mismatch conditions never converge. In our study, however, the two effects seem to occur in two separate latency windows, which suggests that the two effects might be reflecting different processes. An early congruency effect, separate from the N400, has also been reported for 18 -month-olds in Sheehan, Namy & Mills (2007).

For the N200, there are several possible functional interpretations. First, it could be the phonological mismatch negativity effect (PMN; Connelly & Philips, 1994). The PMN, which also has a fronto-central distribution, has been elicited in both auditory as well as picture-word priming studies (e.g., van den Brink, Brown & Hagoort, 2001, and DesRoches et al., 2009, respectively). There are two possible explanations for the PMN: It either reflects a prelexical stage of word recognition based on acoustic input, or a phonological comparison of the input with an expected word form. Both explanations suggest that the PMN reflects processing of phonological form (van den Brink et al., 2001). The N200 in our study could be an instance of the PMN, since it has a similar distribution and timing. Recall that incongruous words differ from congruous words in this experiment already from the first phoneme, since all target words were paired in the training phase with words that differ in onset and vowel. Hence, the early incongruency effect could reflect the phonological mismatch between the expected (congruent) word and the presented (incongruent) word.

Sheehan et al. (2007) also put forward the N300 as a possible origin of the early semantic congruency effect. The N300, with an anterior distribution, has been reported in picture-picture priming studies (e.g., Barrett & Rugg, 1990). Its timing is 100 ms later than the N200, and typically observed in the absence of auditory words, making the N300 an unlikely source for our early semantic congruity effect.

The presence of the N200 effect implies that infants must have predicted the phonological word form. In other words, once infants see a novel exemplar, they generate internally a label for it, even before the label is presented one second later. It is likely that this is the result of the training phase prior to test, the repetitive design of which would further encourage infants to build up expectancies of what is coming next. There is strong evidence from other ERP research in adults that people use prediction to recognize words where appropriate (e.g., van Berkum, Brown, Zwitserlood, Kooijman, & Hagoort, 2005).

Our second semantic congruity effect, found from 400-600ms is, we believe, the classical N400 effect. Whereas the earlier effect reflects a violation of the anticipated phonological word form, the later effect reflects difficulty of integrating the contrasted word with the present picture context. In other words, the N400 is sensitive to the meaning of the word. The standard time window for studying the N400 in adults is 300-500 ms, which indicates a small delay of 100 ms for infants. Moreover, the N400 does not end at 600 ms; at parietal electrodes the effect seems to have a later latency, and at other (mainly right) electrodes it extends to 800 ms. We chose the 400-600 ms range since it is the same time window studied at various ages by Mills and colleagues (e.g., Sheehan et al. 2007). In adults, N400 congruity effects are usually characterized by a posterior distribution. It is on these electrodes that we observe a link with infants' present vocabulary size: the larger the negativity, the more words they comprehend. This is in line with other studies showing a relation between the size of the N400 and present or subsequent vocabulary size (Friedrich & Friederici, 2006, 2010; Torkildsen et al., 2008).

Finding an N400 in nine-month-olds, however, was not predicted based on the line of studies carried out by Friedrich and Friederici (2004, 2005a, 2010). They did not observe a common N400 in their youngest age group, who were three months older than infants in our study. There are several possible reasons why the infants in our study show an N400 whereas their older German peers fail to show such a response. First, the proportion of match versus mismatch differs. In the German studies infants saw three times as many incongruous trials than congruous trials, since there was one condition of congruous trials, but three conditions of incongruous trials (incongruous real word; incongruous non-sense word; and incongruous phonologically impossible non-sense word). This ratio is reversed in the present study: Adding a training phase per block entails that infants saw three times as many congruous than incongruous trials. Not only is it likely that the training phase boosted the word-object associations for each word, but it also enforced priming effects of pictures for words in general. A ratio of more incongruous than congruous trials, on the other hand, might have weakened priming effects when word-object associations are not strong.

Second, we presented a smaller number of words to our infant participants (20 rather than 50 words). Twelve-month-olds might not understand all fifty words to the same extent as their older peers would do when tested with the same design.

Third, words in our study were presented as single words, whereas words in the Friedrich & Friederici design were preceded by an indefinite pronoun. Although infants mainly hear words in continuous speech (e.g. van de Weijer, 1996), exposure to isolated words facilitates initial word learning (Brent & Siskind, 2001; but see Fernald & Hurtado (2006) and Fennell & Waxman (2010) for contrasting findings from older infants).

Of course, infants across experiments also differ in their mother language, with possible language-specific development patterns, but we know of no corresponding linguistic difference that would motivate such an effect. All these differences in experimental design might each have contributed to the absence of an N400 for 12-month-olds in one study, but presence for infants three months younger in the other.

Instead of finding a negativity for incongruous words versus congruous words, Friedrich & Friederici report a 'phonological negativity' effect, larger for congruous words, for all age groups. We did not observe this effect in the test phase, nor was it observed in any of Mills and colleagues' studies. Such an effect, however, was observed in the training phase for repeated words. Hence, it is possible that the word Familiarity effect taps the same neural mechanisms for word recognition as was the case for congruous words for German children, as Friedrich and Friederici suggested (2004, 2005a). Because there were more incongruous than congruous words, 12-month-olds did not process words any further when they did not fit their phonological expectancies. But when the picture context is congruent with the upcoming word, it facilitates recognition of the upcoming word.

Our results are more comparable to the N400-like response observed in American-English speaking 14-17-month-olds as well as adults (Mills et al., 2005). The similarities in timing and distribution are further evidence that infants and adults use similar neural mechanisms for lexical-semantic processing. Together, the observed N200 and N400 imply that infants as young as nine months are already capable of understanding the meaning of early words. They can perform word-to-world mappings even for exemplars they have never seen before.

CONCLUSION

In the current study we investigated ERP responses of 9-month-olds on basic level picture-word pairings. The present research extends the literature in three substantial and significant ways. For *visual categorization*, we observed that the Nc component, associated with visual attention and recognition, is attenuated with repetition. It is only here that we observed an effect of type-token ratio of pictures: The Nc was further decreased when the picture token stays constant. This suggests that the Nc reflects here attention or saliency. For *word recognition*, the word familiarity effect became more negative with repetition, but there was no influence of picture token context, suggesting that infants have identified the concept of each picture before the word was presented (i.e., within a second). For *word-to-world mappings*, infants showed different ERP responses for words that did or did not align with the picture context, which implies that infants were able to map words to novel exemplars as young as nine months. We observed two effects, an early N200 and an N400. The N200 implies that infants predicted the upcoming word form. In other words, when a novel picture of a trained category was presented, infants internally generated the phonological word form before the actual word was presented. The N400 reflects their difficulty of integrating the mismatched word with the supporting picture. Together, our results provide electrophysiological evidence of early word learning.

CHAPTER 2: ELECTROPHYSIOLOGICAL EVIDENCE OF EARLY WORD LEARNING

RAPID RECOGNITION AT TEN MONTHS AS A PREDICTOR OF LANGUAGE DEVELOPMENT

CHAPTER 3

This chapter is a slightly revised version of Junge, C.M.M., Kooijman, V.K., Hagoort, P., & Cutler, A. (submitted): Rapid recognition at ten months as a predictor of language development.

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 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 six and nine 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 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 twelve occurrences 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 the target words during familiarization in this case was also twelve.

Subsequent research focused on various, sometimes conflicting, segmentation cues in the speech signal. Jusczyk, Houston & 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 looking 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 on the moment in time when infants initiate recognition of 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. Infants showed a negativity over left frontal electrodes around 400 ms from onset of the familiarized words, which was not observed with the unfamiliar 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 one to subsequently distinguish between the familiarized word in question and a similar but unfamiliarized word, both presented in continuous speech. But what is the earliest point at which infants can classify a 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 control 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; 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 two 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; Chapter 5 in this thesis) compared children's language scores at three years and their performance at seven months in an ERP speech segmentation task with the same design as Kooijman et al. (2005). Although most seven-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 seven-month-olds who showed the 10-month-old pattern then proved to have higher language quotients at three 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.

METHOD

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 et al., 1993). For each word, we chose from previous studies (Kooijman et al., 2005, 2009) two sentences containing this word in non-initial and non-final position. See appendix 1B for all stimulus materials.

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. 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. Goyet et al. (2010), however, demonstrated that the recognition effect in infants is quite localized. They 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.

Table 3.1 presents an example of the word pair *hommel-mammoet*, over the four conditions of our 2x2 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. In each case they received familiarization with the same word twice, once followed in the test phase by the same word and once followed by the unfamiliarized word; these two familiarizations always involved different utterances so that the same acoustic token was never heard twice. The two tokens were also counterbalanced within each group (giving four lists in total). Each list was presented to seven infants.

The 160 sentences (40 pairs x two words x two sentences per word) were digitally recorded in a sound-attenuating booth by a female native speaker of Dutch, speaking

Table 3.1: *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 brackets. 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.*

Condition		Familiar		Unfamiliar	
		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 curtain)	**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)

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 = 265ms) 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 if necessary. Two loudspeakers presented the auditory stimuli. In segmentation trials a 500 ms interval separated sentence offset and target word. In memory trials, the interval between prime word offset and target word onset was matched to that in the corresponding segmentation trials. 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 (TP9) 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).

Repeated measures analyses of variance (ANOVA) were performed on the mean amplitudes in selected time windows, with Familiarity (familiar vs. unfamiliar), Quadrant (4: left frontal, right frontal, left posterior, right posterior), and electrode (5; left frontal: F7, F3, FT7, FC3, C3; right frontal: F8, F4, FT8, FC4, C4; left posterior: LT, LTP, CP3, LP, P3; right posterior: RT, RTP, CP4, RP, P4) as within-subject variables. This was done separately for each Familiarization Type (memory, segmentation), because the timing of the familiarity effect could differ per condition. 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 future 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 et al., 1993; N-CDI: Zink & Lejaegere, 2001). 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 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 3.1a shows the mean waveforms for words that were versus those that were not presented in familiarization in isolation. (See Appendix 2C for grand average waveforms for all 20 lateral electrodes). 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 ($F(1,27) = 4.72$, $p = .039$, $\eta^2 = .15$; See also Appendix 3B, Supporting Table 1), 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 is 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.

At 10 months: the segmentation condition

Figure 3.1b shows the grand average waveforms for familiarized and unfamiliarized words in the segmentation condition, where the familiarization had involved continuous utterances. (See Appendix 2D for grand average waveforms for all 20 lateral electrodes). 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, η^2 = .10; right frontal: F(1,27) = 0.65, p = .43, η^2 = .02; left posterior: F(1,27) = 1.15, p = .29, η^2 = .04; right posterior: F(1,27) = 0.94, p = .34, η^2 = .03). See also Appendix 3B, Supporting Table 2a).

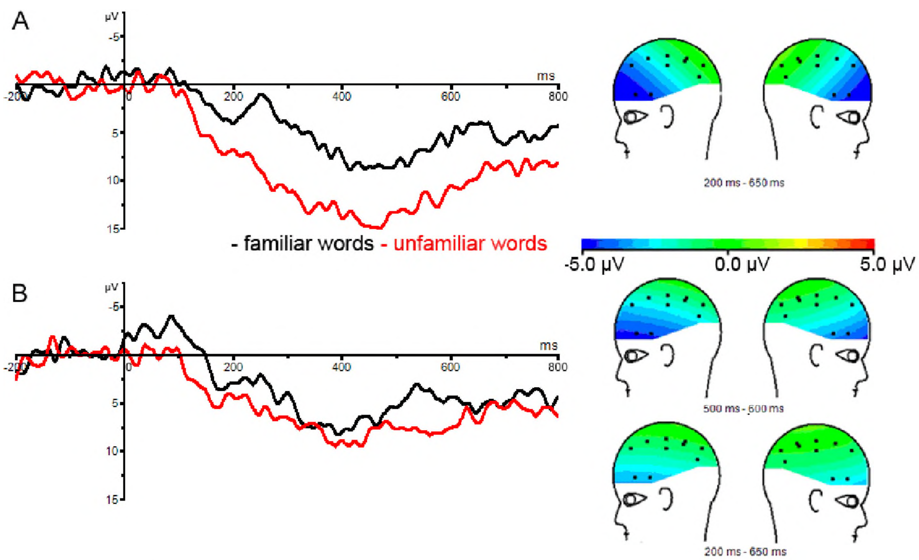

Figure 3.1: *Grand average waveforms for the familiarized and unfamiliarized words at left frontal electrode F7 on the left; negativity is plotted upwards; 0 ms indicates word onset. On the right, isovoltage plots of the familiarity effect (familiarized – unfamiliarized words), corresponding with the selected time windows. 1a. Results of the memory condition. 1b. Results of the segmentation condition.*

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, η^2 = .02; See also Appendix 3B, Supporting

Table 2b.). 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 & 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).

We then compared the two groups, across conditions, on their ability to recognize words by entering 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. (See also Supporting Table 3 in appendix 3B).

[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 similar, no-significant, main effect of Familiarity or interactions 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.

We accordingly examined the ERP results for LV and HV infants separately Figure 3.2 shows the topographical distribution for the Vocabulary Groups for both types of Familiarization. (See also Appendices 2E-H). 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 ($F(1,13) = 7.12$, $p = .019$, $\eta^2 = .35$; see Supporting Table 4a in Appendix 3B). 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 ($F(1,13) = 0.66$, $p = .43$, $\eta^2 = .05$). (See also Supporting Tables 4b and 4c).

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 ($F(1,13) = 15.41$, $p = .002$, $\eta^2 = .54$; cf. Supporting Table 5a in Appendix 3B).

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 3.2 shows that the effect in the segmentation condition is more broadly distributed than in the memory condition. Statistical analyses conform 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 x 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 ($F(1,13) = 8.50$, $p = .012$, $\eta^2 = .40$; See also Supporting Tables 5b and 5c in Appendix 3B, respectively). 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 ($F(1,13) = 7.01$, $p = .020$, $\eta^2 = .35$).

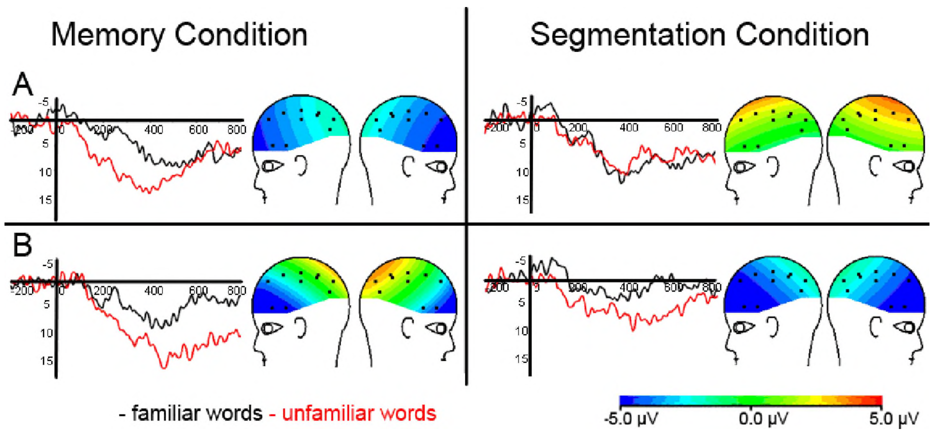

Figure 3.2: *Grand average waveforms, split by Vocabulary Group and Familiarity Type for the familiarized and unfamiliarized words at left frontal electrode F7 on the left; negativity is plotted upwards; 0 ms indicates word onset, with the corresponding isovoltage plots of the familiarity effect (familiarized – unfamiliarized words) for the time window 200 - 650 ms. Figure 3.2A: Results for the infants in the Smaller Vocabulary group. Figure 3.2B: Results for the infants in the Larger Vocabulary Group. Although both Vocabulary groups show a Familiarity effect in the memory condition, only infants with larger vocabularies show a familiarity effect in the segmentation condition.*

Visual inspection of Figure 3.2 further shows that both time course and distribution of the Familiarity effect in the memory condition differs 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 ($F(1,13) = 18.78$, $p = .001$, $\eta^2 = .59$; cf. supporting Table 6a, Appendix 3B), whereas HV infants only show a significant effect on the four left frontal electrodes F3, FT7, F7 and FC3 ($F(1,13) = 5.17$, $p = .041$, $\eta^2 = .29$; cf. supporting Table 6b, Appendix 3B). 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, $p = .004$, $\eta^2 = .48$; see also Supporting Tables 7a and 7b in Appendix 3B for the LV and the HV groups, respectively).

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 3.3A 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 ($r = +0.076$, $r^2 = 0.006$, $p = 0.70$). The memory and segmentation indices themselves are also not related ($r = -0.036$, $r^2 = 0.001$, $p = 0.86$). 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 ($r = -0.54$, $r^2 = 0.29$, $p = 0.003$; $r = -0.47$, $r^2 = 0.22$, $p = 0.014$, respectively).

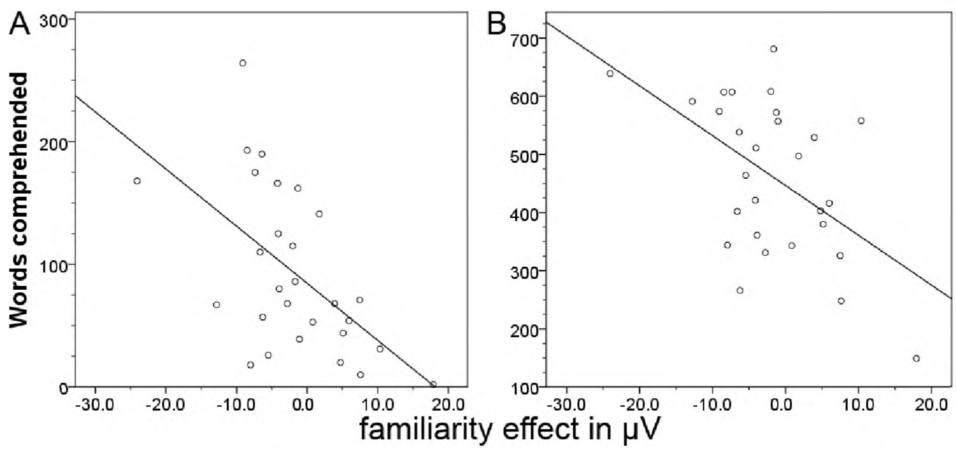

Figure 3.3: *Relation between segmentation ability at 10 months, as measured by the individual amplitude difference (familiarized-unfamiliarized words) over left frontal electrodes in the time window 200-650 ms (segmentation condition), and the number of words understood at 12 (A) or at 24 months (B), respectively.*

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

Table 3.2 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 ($r = -0.54$, $r^2 = .29$, $p = .027$), as is shown in Figure 3B. The larger infants' ERP difference at 10 months, the larger their comprehension vocabulary at age two. The ERP index of the memory condition does not relate to vocabulary size at 24 months.

Table 3.2: *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. Note* $*p \leq .05$. $**p \leq .01$ $***p \leq .001$

Age	Measure	1.	2.	3.	4.	5.	6.	7.
10 months	**0.** Segmentation ability (-1.7 µV, [-24.0, +17.9])	-.04	-.56**	-.59***	-.55**	-.15	-.52**	-.38*
	1. Memory ability (-3.8 µV, [-19.8, +7.1])		+.08	-.02	+.09	+.02	-.14	-.11
12 months	**2.** Items understood (93.0, [2-264])			+.88***	+.99***	+.31	+.59***	+.43*
	3. Phrases understood (14.9, [2-31])				+.85***	+.32	+.74***	+.61***
	4. Words understood (78.1, [0-233])					+.30	+.56**	+.40*
	5. Words produced (5.5, [0-39])						+.36	+.37*
24 months	**6.** Words understood (416.5, [149 – 681])							+.86***
	7. Words produced 326.4, [28 – 676])							

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 two 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; nine- 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, & 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 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, 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 200-650 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 200-500 ms, which further increases from 500-650 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 List 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). This makes it unlikely that HV infants in our study could have used the words already in their vocabulary as anchors. The syllabic structure of these words, on the other hand, could have been a clue 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 socio-economic and parental factors, there was little variation across our infant subject population, but there is always room for variation in ability across individuals.

CONCLUSION

The skill of segmenting words from continuous speech is vital for building a vocabulary and hence unquestionably 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 clear evidence of the link between segmentation skill and vocabulary development: infants who at 10 months rapidly recognize words from continuous speech go on to develop larger vocabularies than their peers, at least to an age of two years.

RELATING RECOGNITION EFFICIENCY FOR WORD FORMS AT 10 MONTHS AND FOR WORD MEANING AT 16 MONTHS

CHAPTER 4

This chapter is a slightly revised version of Junge, C.M.M., Cutler, A., & Hagoort, P. (submitted). Relating recognition efficiency for word forms and for word meaning at 16 months.

ABSTRACT

Most of the words that infants hear occur within fluent speech. To build up a vocabulary infants therefore need to first recognize words by segmenting them from speech. The present study used ERPs to examine whether 10-month-olds can segment word forms from continuous speech and recognize them again in novel utterances. We present electrophysiological evidence that infants can achieve this: The infants show a word familiarity effect for familiarized words relative to unfamiliar words in continuous speech. Brain correlates of speech segmentation ability at 10 months were related to an objective index of recognizing words in fluent speech at 16 months: The larger the size of the word familiarity effect at 10 months, the longer infants at 16 months fixated an object after hearing the spoken object name.

INTRODUCTION

When infants start building up a vocabulary, they need to map word forms to concepts. A successful mapping requires them not only to identify the concept, but also the word form. However, word recognition is not a trivial task for infants.

First, there is the invariance problem (Cole & Jakimik, 1980): The acoustic form of the same word can vary considerably, as it is affected by speaker characteristics (e.g. gender and speaking rate), and the context in which it occurs (e.g., co-articulation and stress). Second, since infants, just as adults, mainly hear multi-word utterances (Morgan, 1996; Van de Weijer, 1998; Woodward & Aslin, 1990), they need to recognize words within a speech stream. This makes word recognition even more challenging, because speech is continuous: the boundaries between individual words in an utterance are not marked by reliable and consistent cues. Figure 4.1 illustrates how hard both problems can be, even when in this case the speaker identity is constant. The three spectrograms represent three different Dutch sentences, each with the same word in mid-position (*hinde* 'doe'). From the three utterances, represented on the left, it is clear that there are no clear pauses in the speech signal to detect the onset or offset of the word. And even when the word *hinde* is extracted from the utterances, the acoustic shape differs in duration and spectral quality, influenced by its position in the sentence and the surrounding phonemes. Similar phenomena can be found in all languages.

There are several cues that can assist infants to segment words from speech. Which cues are more advantageous depends on the native language (Cutler, 2002) and these cues are thus learned through experience. Moreover, they are probabilistic rather than deterministic: no single cue is sufficient to detect word boundaries. Between 7.5 and twelve months, infants have become sensitive to regularities in the perceptual input of speech, such as frequency of occurrence, distribution of stress and phonotactic patterns (Jusczyk, 1999; Saffran, Werker & Werner, 2006). As Jusczyk,

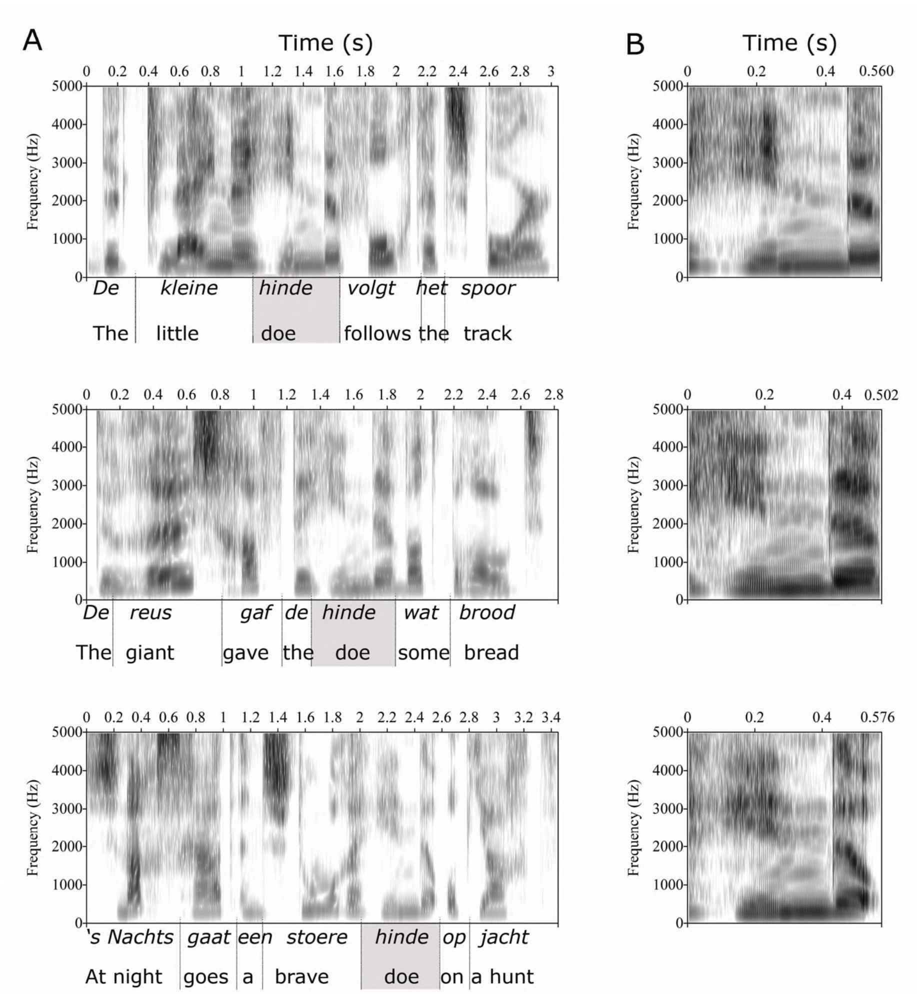

Figure 4.1: *Spectrograms. Figure 4.1A: three Dutch sentences, each with the word hinde in mid-position, spoken by the same native speaker in an infant-directed manner. Frequency of the speech signal is plotted on the y-axis, and time on the x-axis. The lines underneath the spectrograms correspond to boundaries between words, with the Dutch words in italics, and English translations below. The grey box marks "hinde". Most words in each sentence are adjoined continuously, with no pauses. Figure 4.1B shows the three tokens of "hinde" extracted from the utterance on the left. Each token differs in duration and in spectral frequency.*

Houston & Newsome (1999) showed, an important cue for infants from stress-based languages is that a stressed syllable indicates word onset for a majority of words (Cutler & Carter, 1987, for English; Schreuder & Baayen, 1994, for Dutch). Other language-specific cues that infants can exploit to segment speech are the phonetic and phonotactic regularities in their native language (e.g., Mattys, Jusczyk, Luce & Morgan, 1999).

Word segmentation has principally been studied with the behavioural two-stage familiarization-then-test version of the headturn-preference procedure (HPP: Jusczyk & Aslin, 1995). The HPP compares infants' listening time to stimuli of one type versus another, with longer listening times for one type indicating a preference. If infants first hear natural tokens of certain word forms in isolation, they generally, on later presentation, prefer passages containing these familiarized words over those containing similar but unfamiliarized words, so they listen longer to them. This difference in their listening times implies that infants distinguished between passages, and hence have segmented the familiarized words from the speech signal.

A disadvantage of the HPP, however, is that while it provides evidence of the occurrence of word segmentation, it cannot reflect how rapidly this has appeared. In contrast, electro-encephalography (EEG) provides an *on-line* measure of speech segmentation, which enables one to examine the time course as well as the number of times a word is presented before a word is recognized. This method has the additional advantage that no overt behavioural response is required. In infant studies particularly it is difficult to interpret null effects, because it is possible that infants are able to perform a task, yet fail to respond in the predicted way (cf. Aslin & Fiser, 2005).

Kooijman, Hagoort & Cutler (2005) were the first to devise an electrophysiological version of the familiarization-and-test HPP paradigm. They familiarized 10-month-olds with 10 tokens of the same infrequent trochaic word form in isolation, and then recorded event-related potentials (ERPs) to these familiarized word forms, and to matched unfamiliar word forms, in utterances. Due to the lower signal-to-noise ratio characteristic of ERP experiments, more familiarization-and-test combinations were presented than is typical for HPP experiments, but the amount of familiarization per word was the same. The infants' brain responses showed a clear recognition response: Relative to unfamiliar words, familiar words elicited a negativity around 400 ms after onset of the word. Since then, this word familiarity effect has also been reported for slightly older infants from different native languages (French 12-month-olds: Goyet, de Schonen & Nazzi, 2010; German 12-month-olds, Männel & Friederici, 2010).

For both ERP and HPP studies, word segmentation is tested in a two-phase design. Jusczyk & Aslin (1995) showed that infants preferred to listen to continuous speech containing words they had heard in isolation, and also preferred to listen to isolated words which they had heard before in continuous speech. Thus, either the familiarization or the test phase consisted of isolated words, and the other phase consisted of multiple words in utterances. The speech that infants hear, however, comprises mainly continuous speech. Moreover, one of the characteristics of child directed speech is that parents often repeat words, embedded in different utterances (Aslin, 1993; Phillips, 1973; Van de Weijer, 1998).The infant's task is actually to recognize that a continuous utterance contains a word they have previously heard in another continuous utterance. Thus, the utterances in Figure 4.1, which are in fact taken from the materials of the present study, represent a fair approximation of the daily situation in which infants encounter repetitions of words. Recent research suggests that infants at 18 months even recognize word meanings faster in sentence frames than in isolation (Fernald & Hurtado, 2006).

The present study therefore examined whether infants are able to build up a memory trace for words repeated across different natural utterances, and recognize them again, within new utterances. Of course, both processes require that the infants have segmented the speech stream. We measured ERPs, because this on-line measure of word recognition enables us to compare the brain responses involved in building up a memory trace with those involved in distinguishing between familiarized versus unfamiliar words. Just as in the study by Kooijman, Hagoort & Cutler (2005), we tested 28 Dutch 10-month-olds. See Table 4.1 for an example of the familiarization-and-test-block, in which the familiarized word *hinde* is first presented in eight sentences (familiarization phase) before it is contrasted with the unfamiliarized word *krokus* 'crocus' (test phase).

Table 4.1: *An example of an experimental block (with literal English translations between brackets). Target words are underlined.*

Familiarization Phase:	
1.	*Een vogel zag die hinde knielen.* (A bird saw that doe kneel.)
2.	*s' Nachts gaat een stoere hinde op jacht.* (At night the brave doe goes on a hunt.)
3.	*Het hertje hield van haar hinde.* (The little deer loved her doe.)
4.	*Samen vingen zij jouw hinde.* (Together they caught your doe.)
5.	*Daar eet een hinde het gras.* (There a doe eats the grass.)
6.	*De kleine hinde volgt het spoor.* (The little doe follows the track.)
7.	*Naast een hinde loopt een geit.* (Next to a doe a goat is walking.)
8.	*Voor de hinde gaat het lastig.* (For the doe the going is tough.)
Test Phase:	
9.	*Net naast deze krokus ligt wat* (Just beside this crocus there is something)
10.	*Een aardige hinde wijst de weg* (A friendly doe shows the way)
11.	*De reus gaf de hinde wat brood* (The giant gave the doe some bread)
12.	*De grotere krokus is mooier* (the larger crocus is prettier)

To examine the forming of a memory trace, we compared ERPs time-locked to the first two tokens with those of the last two tokens that a word is presented in the familiarization phase. Just as for the word familiarity effect reported for the familiarization phases (which consisted of isolated words) in Kooijman et al. 2005 and in Goyet et al. 2010, we predicted that the more familiar words become the more negative in voltage their corresponding ERPs will be. In the test phase we then compared ERPs for familiarized words with those for unfamiliarized words, thus exploring whether the same infants are able to recognize novel tokens, again within continuous speech, as familiar. Since unfamiliar words are by definition not familiar, we predicted again a word familiarity effect around 400 ms for the familiarized words.

Furthermore we tested for a link between infants' performance in the first speech segmentation task and their language development six months later. There is ample evidence that the ability to segment words in running speech (and to recognize these units as possible word forms) is a crucial step in building up a vocabulary. Both behavioural and electrophysiological indices of speech segmentation ability have been positively related with subsequent language development (behavioural: Newman, Bernstein Ratner, Jusczyk, Jusczyk & Dow, 2006; electrophysiological: Junge, Hagoort, Kooijman & Cutler, 2010 (Chapter 5, this thesis); Junge, Kooijman, Hagoort & Cutler, under review (Chapter 3, this thesis)). However, language development in normally-developing infants, particularly up to 24 months, is often not assessed directly, but by parents filling in a version of the MacArthur-Bates Communicative Development Inventory (CDI: Fenson et al., 1993). Such ratings can be prone to parental biases (Houston-Price, Mather & Sakkalou, 2007; Tomasello & Marvis, 1994). Moreover, most studies that used the CDI as an individual measure report a positive link with task performance. This could indicate the existence of a publication bias: studies that report positive relationships with CDI scores are published, but neutral or negative relationships are not. The second aim of this paper was therefore to test whether speech segmentation ability was also related to an experimentally obtained (and hence objective) index of language development at 16 months that crucially measures infants' ability to recognize (meanings of) words on-line, presented again in continuous speech. Hence, we experimentally assessed the link between early word form recognition and later word meaning recognition, both of which required infants to segment words from continuous speech.

In Experiment 4.2 of the current study, the infants who had taken part in Experiment 4.1 therefore returned at 16 months to participate in a looking-while-listening procedure (LWL; cf. Fernald, Zangl, Portillo & Marchman, 2008). The infants saw pairs of pictures and heard continuous speech in which the name of one of the pictures was presented. The procedure is based on the finding that infants look longer at a visual stimulus that matches audio they hear than at one that does not (Spelke, 1979; Hirsch-Pasek & Golinkoff, 1996). For instance, a child who is looking at a picture of a cow next to a picture of a dog will fixate more upon the cow when hearing the word 'cow'. Infants' looking behaviour can be taken as an index of current language development, because it has been shown that the longer infants look at the correct picture upon naming, the better their vocabulary skills (e.g., Reznick, 1990).

The LWL is akin to the intermodal preferential looking paradigm, but crucially uses a different dependent measure. Preferential looking generates a static measure of accuracy: proportion of looking at target (PTL) divided by total looking time over a large time window of two seconds or more. In contrast, with the LWL one tracks infants' eye movements in response to (continuous) speech over time. Consequently, the LWL, just as ERPs, delivers a dynamic measure of word recognition, reflecting accuracy as well as speed.

In Experiment 4.2 we obtain such on-line measures for infants' processing of known[1] words. In addition, prior to test we presented infants with two novel objects, and paired one of them to a novel label. In the test phase infants then saw pairs of known words as well as pairs of the novel objects, and heard each time a name for one of the objects within an utterance (e.g., "Do you see the cow?" when seeing a cow and a dog). In this way we derived individual on-line measures for known as well as for novel word processing that infants had to recognize in fluent speech.

Both known and novel word processing skills have been related to present and later language development. For instance, Fernald and colleagues (Fernald, Perfors & Marchman, 2006; Marchman & Fernald, 2008) demonstrated that individual differences in infants' speech processing efficiency for known words at 25 months are related to their later level of lexical and grammatical development up to eight years, and other studies have reported a positive link between known word recognition and concurrent vocabulary size (e.g., Hollich & George, 2008; Reznick, 1990; Zangl, Klarman Thal, Fernald & Bates, 2005; but see Swingley & Aslin, 2000; Tan & Schafer, 2005). Infants' ability to recognize novel words has also been related to present or later vocabulary size, although less consistently. This could be due to the task used to assess novel word learning: This link has mainly been demonstrated in studies using the switch task (e.g., May Bernhardt, Kemp & Werker, 2007; Werker, Fennel, Corcoran & Stager, 2002) but not in studies using the preferential looking paradigm (e.g., Swingley & Aslin, 2007; Tan & Schafer, 2005). We therefore expect performance on known trials to be a more valid index of current language ability than performance on novel trials.

[1] We use the term 'known words' here rather than the more frequently used term 'familiar words' to avoid confusion with the processing of familiarized words in our first experiment, in which the same infants were familiarized with word forms that presumably carried no meaning for them.

Comparing across experiments, we assess whether the size of infants' familiarity effect for word forms at 10 months (Experiment 4.1) is related to their efficiency in recognizing known and novel words at 16 months (Experiment 4.2). We expect effects to be more likely for known words, and possibly to appear also for novel word processing.

EXPERIMENT 4.1

METHOD

Participants

Twenty-eight 10-month-old infants from Dutch monolingual families participated (mean age = 307 days, age range = 293-319 days; 16 female). An additional 13 infants were excluded from further analysis because of too few artefact-free trials (n= 8); fussing (n=1); refusal to wear the cap (n=3) or computer problems (n=1). All infants were reported to have normal development and hearing, with no history of language or neurological impairments in the immediate family. The majority had college-educated parents. Infants were recruited from the Nijmegen Baby Research Center Database. Parents signed informed consent forms, and received 20 euro and a photograph of their child taken after the experiment in appreciation of their participation.

Materials

Table 4.2 shows the ten pairs of low frequency trochaic words (from here onwards: target words), selected from the CELEX Dutch lexical database (Baayen, Piepenbrock & van Rijn, 1993). The target words and their component syllables were distinctive from each other and unlikely to be familiar to the infants. We created 12 sentences for each target word. We manipulated the position of the target word in the sentence (measured in syllables): a target word could appear no more than twice in the same position in a sentence (measured in syllables). Sentences comprised on average 5.75 words (SD = 0.79; range 4-8), which translated into an average of 8.21 syllables (SD = 0.81; range 6-10). A full list of experimental materials is available in Appendix 1C, Table 1. The sentences were recorded in a sound-attenuating booth by a native Dutch female speaker in an animated child-directed manner, and sampled to disk at 44.1 kHz mono. Mean sentence duration was 2665 ms (SD = 318; range 1875 - 3577). The mean duration of the target words was 697 ms (SD = 112; range 501-999). The onset of the target words was labeled based on auditory and visual inspection using PRAAT software (Boersma & Weenink, 2005).

Table 4.2: *the ten pairs of the Dutch trochaic target words used in Experiment 4.1, with English translations in brackets.*

1	*monnik*	(monk)	*bellers*	(callers)
2	*pudding*	(pudding)	*hommels*	(bumblebees)
3	*gieters*	(watering cans)	*drummer*	(drummer)
4	*sultan*	(sultan)	*pelgrims*	(pilgrims)
5	*hinde*	(doe)	*krokus*	(crocus)
6	*otters*	(otters)	*sitar*	(sitar)
7	*fakirs*	(fakirs)	*ronde*	(round)
8	*mosterd*	(mustard)	*krekels*	(crickets)
9	*lener*	(borrower)	*mammoet*	(mammoth)
10	*gondels*	(gondolas)	*zwaluw*	(swallow)

Procedure

Infants listened to 20 familiarization-and-test blocks. Each familiarization phase consisted of eight different sentences, each containing a token of the same trochaic word. This was followed by a test phase of four randomly presented sentences, two containing the familiarized word (familiarized condition), and two containing a non-familiarized trochaic word (unfamiliarized condition). The interval between sentences was 2000 ms.

We counterbalanced within subjects which member of each word pair appeared in the familiarization phase: The familiarized words in the first half of the experiment were presented as unfamiliar words in the second half of the experiment, and unfamiliar words in the first ten blocks were the ones that became familiarized in the last ten blocks. This entailed, of course, that infants received in one condition an 'unfamiliarized' word that they had heard ten blocks before as a familiarized item. Goyet et al., (2010), however, demonstrated that the recognition effect in infants is quite localized in time. They succeeded in finding a word familiarity effect (familiarized versus unfamiliarized) in an experiment involving only four target words, each presented in up to five familiarization phases of ten isolated tokens. Further, any consequent attenuation of the familiar/unfamiliar difference would of course reduce our chance of finding a significant effect. Moreover, although words were repeated across test phases, the sentences in which they occurred were always novel.

To avoid item-specific and order effects, we compiled four versions of the experiment, counterbalancing the order in which experimental blocks were presented, and the sentences in the test phase (i.e. the same test sentences that belonged to the familiar condition for half of the infants belonged to the unfamiliar condition for the other half of the infants, and all infants heard all sentences). Each version was presented to seven infants.

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. Sentences were presented at an intensity of 65 dB through two loudspeakers placed 1.5 m in front of the child. ERPs were time-locked to the onset of target words. A parent sat by the child, listening to a masking CD through closed-ear headphones. Breaks were taken when necessary. The experiment lasted about 18 minutes, and a whole session about an hour. After the experiment, parents were given an infant version of the Dutch CDI (N-CDI: Zink & Lejaegere, 2001) and returned it filled in within two days. The infant version tests vocabulary comprehension and production of 31 typical utterances and 434 words divided over 19 semantic categories. One parent did not return the N-CDI.

EEG Recordings and pre-processing

EEG was recorded with a sampling rate of 500 Hz, using an infant-size BrainCap with 23 inserted Ag/AgCl electrodes, placed according to the extended 10-20 system (F7, F3, Fz, F4, F8, FC5, FC1, FC2, FC6, T7, C3, Cz, C4, T8, CP5, CP1, CP2, CP6, P7, P3, Pz, P4, P8). Vertical eye movements and blinks were monitored via a supra- to sub-orbital bipolar montage and horizontal eye movements via a right-to-left canthal bipolar montage. Electrodes were referenced online to the left mastoid and re-referenced 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 signal was filtered with an on-line filter of 0.01-200 Hz and an off-line filter of 0.1 - 30 Hz. Trials were time-locked to the onset of target words.

Whenever there was a break midway in a familiarization-and-test-block (e.g., when the child had a small break to eat something), we rejected the remainder of trials in a block, because Goyet et al. (2010) demonstrated that infants show a recognition effect only for words presented in the immediate familiarization phase prior to test. Individual trials with a baseline of 200 ms were furthermore screened for artefacts from 200 ms before to 1000 ms after word onset. Trials were automatically rejected when amplitudes exceeded +/- 150 μV, and manually rejected when we detected clear correlations with the eye channels or activity in the right mastoid during recording. The person performing the manual artefact rejection of the remaining trials was blind to the conditions of the experiment. For each infant, we calculated average waveforms per condition, with a minimum of ten artefact-free trials per condition. Infants contributed on average 15.5 (range 10.7 - 25) artefact-free trials on the four examined conditions (maximum 40).

Statistical analyses

For both the familiarization and the test phase, we compared the ERPs time-locked to target words for familiarized versus unfamiliarized words: for the familiarization phase, between the first two (sentence 1/2; unfamiliarized) versus the last two presentations (sentence 7/8; familiarized); and for the test phase, between familiarized and unfamiliarized words. We examined the familiarity effect separately per phase, because building up a memory trace might be a slower process than the subsequent mapping of a novel token to this memory trace; consequently, the timing of a recognition response could differ. 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 (familiarized vs. unfamiliarized), quadrant (4: left frontal, right frontal, left posterior, right posterior), and electrode (5; left frontal: F7, F3, FT7, FC3, C3; right frontal: F8, F4, FT8, FC4, C4; left posterior: LT, LTP, CP3, LP, P3; right posterior: RT, RTP, CP4, RP, P4) as variables. For all ANOVA tests, we used the Huynh-Feldt epsilon correction and reported original degrees of freedom, adjusted p-values, and adjusted effect sizes (partial eta-squared: η^2). We only report main effects of familiarity and interactions with familiarity.

RESULTS

Familiarization phase

We first established whether 10-month-olds were able to build up a memory trace for words repeated through the eight different sentences in the familiarization phase by comparing the first two times (unfamiliarized) with the seventh and eighth time (familiarized) a word was presented. Figure 4.2A shows the grand average waveforms for familiarized and unfamiliarized words, time-locked to the onset of the target word in each utterance. (See Appendix 2I for grand average waveforms for all 20 lateral electrodes). From 300 ms onwards, familiarized words elicited, as predicted, a larger negative amplitude than unfamiliarized words. Based on visual inspection and on previous studies on auditory word processing (Kooijman et al., 2005; Mills, Conboy & Paton, 2005) we selected two time windows for further inspection: a mid-latency time window of 350-500 ms (word familiarity effect, N350-500), and a later time window of 600-900 ms (N600-900). Figure 4.2B plots the distributions of the two effects.

The time window of 350-500 ms is the same time window that Kooijman et al. (2005) report for the familiarity effect in their test phase (consisting of sentences). Statistical analyses show that there is a main effect of familiarity ($F_{1,27}$ = 4.82, p=.037, η^2 = .15), which is widely distributed (i.e., no interactions with anterior/posterior, hemisphere or electrodes; $F_{1,27}$ < 1.77, p >.19; see Supporting Table 1a from Appendix 3C). We analyzed the exact onset of this effect by performing additional paired t-tests for each electrode (familiarized versus unfamiliarized) on bins of 50 ms with an overlap of 40 ms. Significance (p <.05) on five consecutive 50ms bins was considered evidence for onset of the familiarity effect (cf. Kooijman et al., 2005). This criterion was reached in the latency range of 350-380 ms for 10 of the 23 electrode sites (F3, F4, F8, Fz, FC1, FC6, CP1, P3, P4 and Pz).

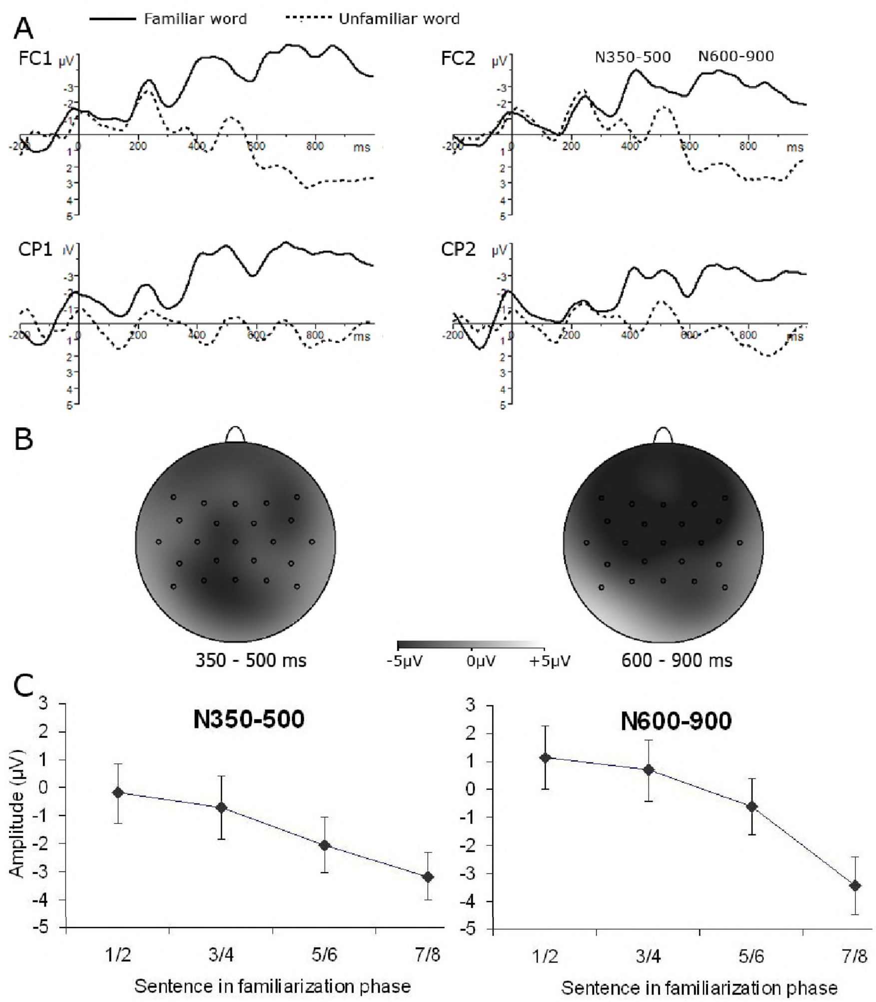

Figure 4.2: *Results of the familiarization phase. Figure 4.2A: Grand average waveforms time-locked to the onset of familiar and unfamiliar words for a left and right frontal (FC1/2) and for a left and right posterior electrode (CP1/2) .(In this and all following ERP figures in this Chapter, an additional 8Hz low-pass filter has been applied for illustrative purposes, and negativity is plotted upwards). Figure 4.2B: distribution plots (familiar - unfamiliar) of the examined time windows. Figure 4.2C: The ERP for familiarized words (averaged over twenty lateral electrodes) for both selected time windows is graded and becomes more negative the more often a word is presented.*

Using the same time window of 350-500 ms, we subsequently calculated mean amplitudes for each two successive target words presented in the trials between the beginning and the end of the familiarization phase (i.e., in sentences 3/4 and in sentences 5/6). Figure 4.2C (left) shows that the more often a word is presented, the more negative the amplitude of its corresponding ERP becomes. Pair-wise comparisons revealed that infants needed to hear seven to eight tokens of a word before the corresponding ERPs were significantly different from those corresponding to the first two times they hear this word ($t(27) = 2.196$, $p = .037$; other comparisons $p > .2$; see also Supporting Table 2, Appendix 3C).

In the later time window (600-900 ms) there was again a significant difference between familiar and unfamiliar words ($F_{1,27} = 10.8$, $p=.003$, $\eta^2 = .29$), with the N600-900 to familiarized words being more negative than to unfamiliarized words. (See Supporting Table 3, Appendix 3C). There was a significant interaction of familiarity by anterior/posterior ($F_{1,\ 27} = 4.56$, $p=.042$, $\eta^2 = .14$): Separate analyses for anterior and posterior quadrants show that this effect is stronger for anterior quadrants, although it is significant ($p <.05$) for both anterior as well as for posterior electrodes (anterior quadrants: $F_{1,27} = 10.72$, $p=.003$, $\eta^2 = .28$; posterior quadrants: $F_{1,27} = 6.93$, $p=.014$, $\eta^2 = .20$). Here, too, we observe that the more often a word is repeated, the more negative the N600-900 becomes (see Figure 4.2C, right).

Test phase

We then examined whether the 10-month-olds showed a different brain response for familiarized words than to unfamiliarized words, presented in novel utterances. Figure 4.3A plots the grand average waveforms of the target words that had been presented in the preceding familiarization phase (familiarized) or not (unfamiliarized words; See also Appendix 2C, Figure 2).

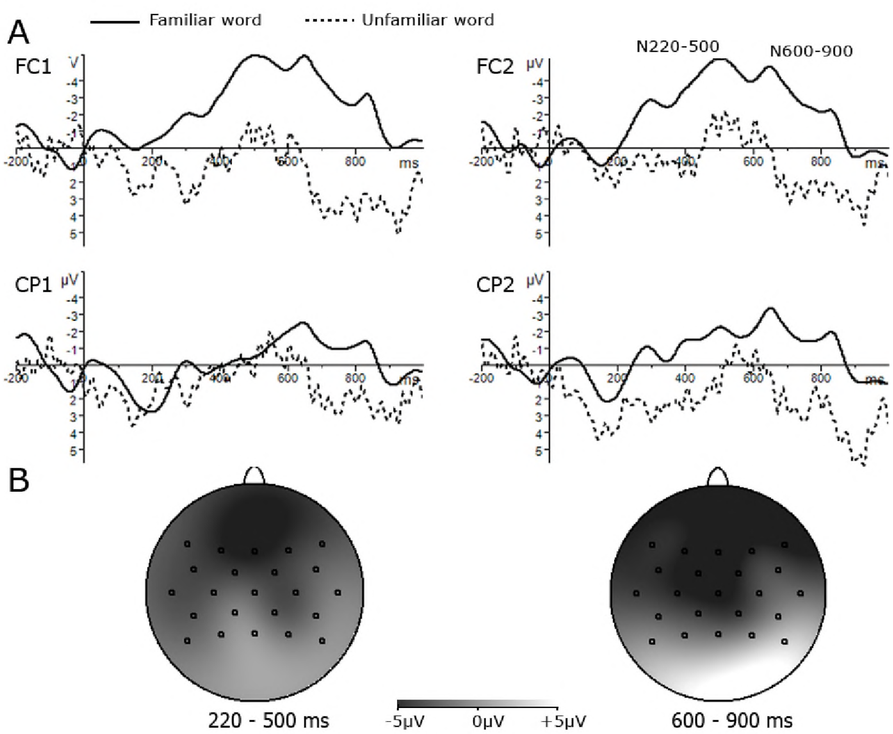

Figure 4.3: *Results of the test phase. Figure 4.3A: Grand average waveforms time-locked to the onset of familiar and unfamiliar words for a left and right frontal electrode (FC1/2) and a left and right posterior electrode (CP1/2). Figure 4.3B: distribution plots (familiar - unfamiliar) of the examined time windows.*

As with the results for the familiarization phase, familiarized words in the test phase showed a greater negative deflection than unfamiliarized words in two time windows, but visual inspection shows that the onset of this familiarity effect is somewhat earlier. We therefore chose the time window 220-500 ms for further inspection. We also examined the time window 600-900 ms, in which the ERPS to familiarized words elicited again a larger negative amplitude than those to unfamiliar words.

In the early time window (220-500 ms), there is a main effect of familiarity ($F_{1,27}$ = 5.04, p=.033, η^2 =.16), again in a negative direction, which is more pronounced over anterior than posterior electrodes (interaction of familiarity by anterior/posterior: $F_{1,27}$ = 4.41, p=.045, η^2 = .14; for anterior quadrants: $F_{1,27}$ = 6.30, p=.018, η^2 = .19; for posterior quadrants: $F_{1,27}$ = 2.29, p=.14, η^2 = .078; for more details see Supporting Table 4a, Appendix 3C). Onset analyses, similar as those carried out for the familiarization phase, revealed that this effect started in the latency range 220-250 ms for four anterior electrodes (F3, F4, Fz, C4). As predicted, this familiarity effect had the form of an increased negativity for familiarized words.

For the later time window (600-900 ms) we observed a significant effect of familiarity ($F_{1,27}$ = 6.25, p=.019, η^2 = .19), again more pronounced over anterior than posterior electrodes (interaction of familiarity by anterior/posterior: $F_{1,27}$ = 7.76, p=.010, η^2 = .22; for anterior electrodes: $F_{1,27}$ = 9.12, p=.005, η^2 = .25; for posterior electrodes: $F_{1,27}$ = 1.51, p=.23, η^2 = .053; see Supporting Table 4b, Appendix 3C).

Linking ERPs with present CDI scores

According to parental report for the 27 children for whom we had CDIs, the 10-month-olds understood on average 68 items (range 1 – 352) and produced 2 words (range 1 – 11). Both measures of word comprehension and production were positively skewed and had a kurtosis value of 7.07 and 3.94, respectively, and deviated significantly from the normal distribution (*Shapiro-Wilks* = 0.72 and 0.62, df = 27, p <.001, respectively). We therefore used non-parametric correlations to examine current vocabulary size with word segmentation ability as indexed by the size of the word familiarity effect in the test phase over frontal electrodes in the 220-500 ms time window. Neither receptive nor productive vocabulary size was related to the size of this ERP effect (*Spearman's* R = -.092, p = .65; *Spearman's* R = -.181, p = .37, respectively).

DISCUSSION

The current experiment examined whether 10-month-olds' brain responses differentiated between familiarized and unfamiliarized words presented within utterances. Infants were first presented with blocks of eight different sentences, each containing a different token of the same target word (familiarization phase). Subsequently, infants listened to four novel sentences (test phase), two containing a novel token of the familiarized word, and two containing an unfamiliar word. Even though these target words were low-frequency words, and therefore presumably meaningless to the infants, our first finding is that over the course of the familiarization phase, ERPs time-locked to the onset of target words became more negative. Our second finding is that similar results were obtained for the test phase: familiarized words elicited more negative ERPs than unfamiliarized words did.

For the familiarization phase we compared ERPs for the first two repetitions versus the last two repetitions, and for the test phase we compared ERPs for familiarized versus unfamiliarized words. For both comparisons, we observed this increased negativity for familiarized words across two time windows: in a mid-latency time window (word familiarity effect), and in a later time window (N600-900).

The word familiarity effect started around 350 ms for the familiarization phase, but around 220 ms for the test phase. The form of these early recognition responses across the two phases are similar in timing and polarity as the familiarity effect for words presented in continuous speech that Kooijman and colleagues (2005) first observed, also in infants of 10 months old. We therefore believe that both early effects in the present study reflect speech processing, in particular the recognition of the familiarized word.

However, the early effects differ in two ways from each other. First, as indicated above, the word familiarity effect started earlier in the test phase than in the familiarization phase. Second, the distribution of the effect in the test phase seemed smaller and restricted to anterior electrodes, compared to the same effect of the familiarization phase, which was broadly distributed. Both differences suggest that there is an increased ease of word recognition in the test phase, compared to word recognition in the familiarization phase. A more focused distribution, reflecting that word recognition might require less neuronal resources, has been linked to better word processing skills (e.g., Mills, Conboy & Paton, 2005).

Similarly, when Kooijman et al. (2005) found that infants initiated an earlier recognition response for words presented in isolation than for the same words subsequently encountered within continuous speech, they attributed this difference to the difficulty of the situation in which word recognition must be achieved. In the present study, 10-month-olds first needed to build up a memory trace for words only presented in continuous speech, from scratch. This situation is presumably more challenging than the situation in the test phase, in which the same infants then needed to map novel presented tokens of familiarized words to this memory trace. Hence, the differences in distribution and timing of the word familiarity effect might reflect the additional benefit for word recognition in the test phase relative to the familiarization phase, in the current study. Nevertheless, in both cases 10-month-olds initiated a recognition response on hearing only part of the familiarized word, since target words were on average 697 ms long.

In a later time window, we observed a N600-900 for familiarized words compared to unfamiliar words. Although Kooijman and colleagues in their studies (Kooijman et al., 2005; Kooijman, Hagoort & Cutler, 2009) did not report such a slow negative wave, it is noteworthy that other infant auditory studies have reported such late effects, with increased negativity for familiar words, besides early familiarity effects (e.g., Conboy & Mills, 2006; Mills, Coffey-Corina & Neville, 1997; Mills et al. 2005; Torkildsen et al., 2008; Zangl & Mills, 2007). For instance, Mills et al. (1997) measured ERPs to known versus unknown words (as rated by parents) in 13-to-17-month-olds as well as in 20-month-olds. Although both age groups showed an increased negativity for known words in the 200-350 ms time window, only the younger age group showed an additional frontally distributed slow negative wave from 600-900 ms for known words. The N200 and N350 were taken as the word familiarity effect, but the latter as an instance of the Negative Central (Nc) effect, indexing attention (Courchesne, Ganz, & Norcia, 1981; Nelson, 1994). Consequently, Mills and colleagues hypothesized that the two effects observed in their study reflect different processes, with the N200-350 ms indexing meaning or word familiarity, and the N600-900 indexing attention and integration of the stimulus.

Note how similar the pattern of significant results reported in the Mills et al. study (1997) is to the pattern reported in our study. Although the former study examined known-word processing in a slightly older age group and we have examined familiarized-word form processing within continuous speech for 10-month-olds, both studies distinguished an early and a late effect, with similar polarity and distributions for known/familiarized words versus unknown/unfamiliarized words. Of course it is also possible that the two effects in our study are in fact one elongated effect, starting at 220 ms and ending at 900 ms. Both early and late effects have similar scalp distributions across the two time windows tested, which is broad for the familiarization phase, but more focal to anterior electrodes for the test phase. However, as mentioned before, other ERP studies on infant word processing skills have also reported both effects as separate. It is the early effect, indexing word familiarity, that has consistently been linked with vocabulary (Conboy & Mills, 2006; Mills et al., 2005; Torkildsen et al., 2009; Zangl & Mills, 2007).

In sum, 10-month-olds' brain potentials are very similar when they are building up a memory trace for words repeated over sentences, as when they recognize these words subsequently, again in a sentence context. In both cases, their ERPs for familiarized words are more negative than their ERPs for unfamiliarized words across two time windows. The (early) word familiarity effect suggests that the infants have recognized the words as familiar. The Nc-effect suggests that infants then increased their attention for familiarized words. Since we believe that the former effect reflects word recognition, we took the N220-500 (from the test phase) as an index of infants' ability at 10 months to recognize words in continuous speech.

The size of the word recognition effect in the test phase, nevertheless, does not correlate with infants' concurrent receptive vocabulary size, as estimated by their parents. This could be because parental ratings might have been subjective and noisy. In Experiment 4.2 we examine the relationship between the word familiarity effect at 10 months and word processing skills in a more objective way by retesting the same infants at 16 months, by which time their vocabulary has increased up to a point that mastery of certain words can be assumed.

EXPERIMENT 4.2

To test whether the word familiarity effect observed in Experiment 4.1 was related to later language development, the same infants returned at 16 months to our lab, to participate in an LWL procedure, measuring both known and novel word processing skills. The novel word learning task was slightly adapted from Swingley & Aslin (2007, Experiment 4.2). In that study, 19-month-olds saw two novel objects equally often, but learned the mapping of word and object for only one object. Learning to map only one label to one object is supposedly easier to achieve than learning two labels for two objects. In contrast to the Swingley & Aslin study, infants in the current study were three months younger, making the task more challenging, and hence more sensitive to individual differences.

METHOD

Participants

Of the original 28 infants tested in Experiment 4.1, 25 children (14 girls) participated successfully in Experiment 4.2; one child was out of reach, one child was inattentive during the task, and one child was excluded due to equipment failure. The children ranged from 15; 24 (months; days) to 16; 24, with a mean age of 16; 02.

Stimuli

The visual stimuli consisted of novel and known objects. Figure 4.4 shows the two stuffed toys used as the novel objects. The labeled one was a soft, bright yellow toy designed to be shaped like a liver, with eyes and a mouth. The label assigned to it was *tiek* (a nonword in Dutch). The second object was a soft, bright green toy with eyes and a tail, designed to look like a sea sparkle. This novel object was not labeled. Both toys were roughly of equal size (about 15 by 15 cm) and rated by the parents as never seen before. For the known objects we selected four animate (baby, cat, cow, and dog) and two inanimate objects (car and ball). Parents were asked to estimate how well their child would understand each known word on a scale from 1 (definitely not) to 5 (definitely yes). Mean ratings for each word ranged between 4.12 (for cow) and 4.72 (for ball), indicating that these were well-known objects. The visual stimuli, presented on the screen in the eye-tracking task, consisted of digitized photographs of these novel and known objects on a dark grey background. In order to avoid too much repetition of pictures, we added variety by using three different picture tokens for each known object.

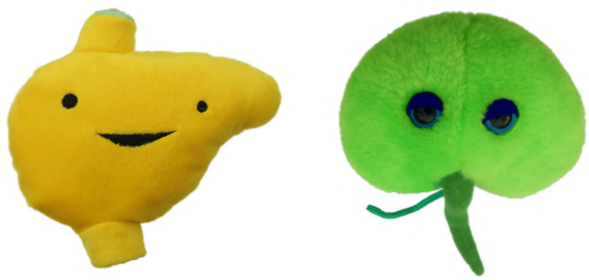

Figure 4.4: *The novel objects: On the left the yellow one that received a label, on the right the green one that only received general comments.*

The auditory stimuli were digitally recorded in a soundproof booth, sampled at 44.1 kHz mono to disk. A native female speaker (different from the one in Experiment 4.1) uttered the stimuli in a child-directed manner. The sentences used for teaching the novel word *tiek* [tik] were as follows: *Dit is een tiek. Tiek! Een tiek. Tiek! Zie je de tiek?* ("This is a tiek. Tiek! A tiek. Tiek! Do you see the tiek?"). The sentences used for commenting upon the other novel word were: "*Dit is leuk. Kijk! Mooi he? Ja. Zie je dit?*" ("This is fun. Look! Pretty, isn't it? Yes. Do you see this?"). For each of the known trials in the familiarization phase, infants heard a token of the carrier phrase "*Kijk een…*" ("Look, a …"), followed by the target (i.e., [ku] 'cow'; [ɦɔnt] 'dog'; [pus] 'cat'; [bebi] 'baby', [ʌuto] 'car' and [bɑl] 'bal'. For filler items, we used the non-existing label *paas* [pas] in the test phase to refer to the non-labeled object. To avoid too much repetition for the sentences in the test phase, we used three different carrier sentences per target, both for novel and for known words. These were as follows: "*Zie je de* [target]?"; "*Waar is de* [target]?", "*Kijk naar de* [target]!" ("Do you see the [target]?"; "Where is the [target]?"; "Look at the [target]!"). Mean target duration within test sentences was 736 ms (SD = 117, range 578 – 896).Target words were also recorded in isolation, with mean durations of 660 ms (SD=147, range 382 – 789).

Procedure

Infants first played for a few minutes with the novel objects they had never seen before. This generally entailed letting the infants put the objects in and out of a box, or handing the objects to an adult and back. The objects were only generally introduced: the objects were not labeled. The parent was also instructed not to give any object a name or compare it to a known object (i.e., the green sea sparkle to an apple).

Subsequently, we moved to a dimly-lit experimental room in which the infants participated in an eye-tracking experiment. Infants sat on their parents' laps, while their parents were wearing head-phones with masking music and were instructed not to interfere. The eye-tracking task consisted of two blocks: a training phase followed by a test phase.

During the training phase, infants saw each novel object four times, but as noted, only one of the objects received a label. Interspersed with the novel trials were six trials, each presenting a different known object in isolation. Known trials lasted three seconds, and novel trials lasted 7.5 seconds. After an initial silence of 500 ms, the auditory stimulus was played. The novel-labeled- and novel-unlabeled-trials were matched for onset and duration of auditory stimuli. Hence, although infants saw both novel objects equally often and heard an equal amount of auditory information, there were in total twenty times in which the novel object was paired with its label in the labeled trials, yet none in the unlabeled trials. In order to keep attention throughout the training phase, both known and novel trials ended with a wiggle of the object over 500 ms.

The test phase comprised 42 trials: 18 known trials and 24 novel trials (12 asking for 'tiek', 12 filler trials asking for the previously not-labeled object by the name 'paas'). Each trial began with the simultaneous presentation of two pictures, positioned at the left and the right of the screen and centred vertically. The two pictures remained on the screen until the end of the trial at 5000 ms. The auditory stimulus was played such that the first onset of the target word starts at 2500 ms, and that the second token (in isolation) followed 750 ms after the sentence.

Novel objects were always presented together, and known objects appeared with other known objects in a fixed pairing (cow with dog; cat with baby; ball with car), counter-balancing side of presentation and carrier sentence. Each picture token served equally often as a target and a distractor, and was always paired with the same object. We also played attention grabbers (e.g., an increasing circle with cheerful music) after every three to four trials. Trials occurred pseudo-randomly, with the restriction that the same picture was never presented consecutively, and that there were no more than two novel trials in a row. Because of our focus on individual differences, we used a consistent order of trials to avoid variation that might arise from different novel pairings or item orders. See Table 2 in Appendix 1C for the order of the stimuli in the training and test phase. After the experiment, which lasted about six minutes, parents filled in the same CDI as in Experiment 4.1 in this chapter.

Apparatus

An infrared corneal reflection eye tracker (Tobii 1750; Tobii Technology, Stockholm, Sweden) measured the gaze of both eyes at a sampling rate of 50 frames per second (with an average accuracy of 0.5° visual angle). The Tobii 1750 was integrated in a 17 inch flat-screen monitor on which the stimuli were shown. This monitor was mounted on an adjustable arm, so that the screen could be positioned about 60 cm in front of the infant's face. We used a 9-point calibration procedure, in which an expanding-contracting circle paired with a sound appeared in every position of a three-by-three grid of white dots on a black background. The experiment started when calibration for at least eight out of nine points was successful.

Statistical analyses

Measures were calculated separately for known trials and for novel-*tiek*-trials. First we analyzed group performances, to assess whether the task was valid. Each test trial was therefore divided into two phases: the pre-naming phase measured from the onset of the display (including the carrier phrase up to the onset of the target word: 0-2500 ms) and the post-naming phase from onset of target word up to end of trial (2860-5000 ms), taking into account the 360 ms delay that infants need to initiate an eye movement in response to speech (Fernald, Swingley, & Pinto, 2001; Swingley & Aslin, 2000). Only trials during which infants fixated both the target and the distractor in the pre-naming phase are taken into account for analyzing children's looking behaviour. For group measures we used the proportion of total looking at target (PTL). The PTL is calculated for both phases separately by dividing the total time spent looking at the target by the total time looking at either target or distractor. The delta PTL reflects the added proportion of looking at target in the post-naming phase compared to the pre-naming phase.

For individual measures we calculated the mean latency that infants shifted their gaze to the other object, based on where they were looking at the time of critical word onset. Because infants cannot know which of the two objects will be labeled, about half of the time they will be looking at the target picture (target-initial trials), and half of the time at the distractor picture (distractor-initial trials). The correct response is then to continue fixating the target on target-initial responses, but to shift the eyes to the target picture on distractor-initial response (Schafer & Plunkett, 1998; Fernald, Perfors, & Marchmann, 2006). Hence, for target-initial trials, the latency to switch to the other object (LS) reflects accuracy, with larger latencies reflecting longer fixations at target, yet the LS for distractor-initial trials reflects reaction time, with shorter latencies reflecting faster shifts to target (Fernald et al., 2008). We used the difference in LS for target- versus distractor-trials (delta LS) as a combined on-line measure for word recognition. The individual measures were then correlated with the word familiarity effect at 10 months.

RESULTS

Results from the eye-tracking task

Individual measures can only be interpretable in terms of their relation to the performance within a group. Figure 4.5 shows the overall results of the current eye-tracking experiment. In the pre-naming phase infants are supposed to perform at chance (i.e., to look at the target half of the time); upon hearing the matching label, they should increase their looks at target. Although infants showed the expected pattern for known words, with a mean of +7.8 % (SD 9.6%) increase in looking at the target after hearing the word ($t(24) = 4.02$, $p < .001$), they did not show this pattern for the novel word (mean = -5.8%, SD = 16.7% ; $t(24) = -1.81$, $p = .083$). In fact, even in the pre-naming phase they had a significant preference for the unnamed object (mean PTL = 44.3%, SD =8.7%; $t(24) = -3.26$, $p = .003$), and when they heard the label, they decreased their looks to the target even more. Seventeen out of the 25 infants looked less at the correct novel object upon naming. In contrast, twenty infants looked longer at the correct known object in the test phase.

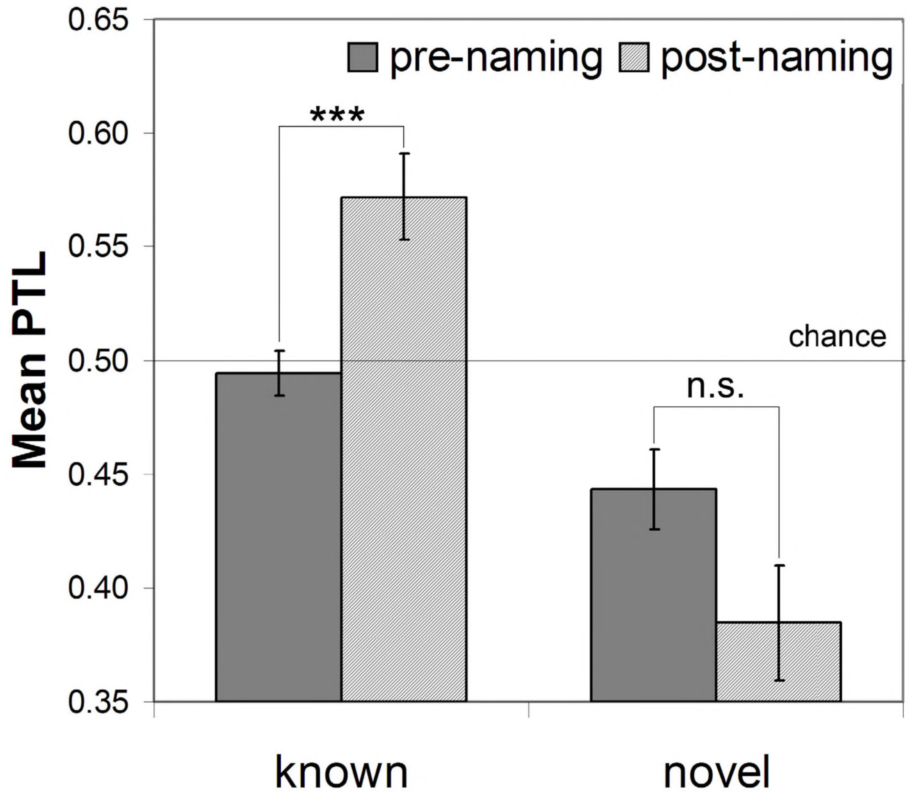

Figure 4.5: *Group performance at 16 months, split by known and novel-only trials. (PTL = proportion looking at target; error bars are 1 standard error from the mean; *** p <.001; n.s. = not significant).*

Recognizing word forms at 10 months and known words at 16 months

Since the group results for novel trials concerning the baseline period already suggest that infants prefer the unnamed object, and since it is unclear what, if not the label, drives the motivation of the infants to look more at the unnamed object in the test phase, it is not valid to equate infants' performance on novel word trials in this eye-tracking task with the ability to learn novel words. Moreover, in contrast to Tan & Schafer (2005), we observed no relationship between the added PTL (between pre- and post-naming phase) for novel trials and that for known trials (r (25) = +.038, p =.86).

Performance on the eye-tracking task on known word processing, on the other hand, appears to be a good individual measure for infants' skill at dealing with known words. First, performance in the pre-naming phase provides a good baseline: the PTL is not significantly different from chance (t(24) = -0.60, p = .55). Second, the majority of the infants showed the expected increase in looking time at target after hearing the target word. Moreover, there is a trend in the data indicating that infants shifted their gaze faster towards than away from the target (t (24) = 1.59, p = .07, one-tailed; cf. Schafer & Plunkett, 1998). The mean delta LS (i.e. the difference in latency to switch gaze for target- versus distracter-initial trials) was + 105 ms (SD 361); in other words, upon hearing the label, infants continued to fixate the correct object longer than when they started the fixation at the distracter object. Since the aim of Experiment 4.2 was to link infants' performance here with their earlier performance in Experiment 4.1, we will concentrate on the dynamic measures for known word processing.

Table 4.3 presents the Pearson's correlation coefficient matrix of the Experiment 4.1 and 4.2 processing indices for the individual measures. The index of speech segmentation ability at 10 months is the size of the word familiarity effect at test, which had a negative amplitude. We used delta LS as the index of known word recognition in real-time at 16 months, since it captures both accuracy and speed. There is a clear relation between the ERP correlates of speech segmentation skill and the behavioural correlates of known word recognition skill six months later: the larger the word familiarity effect, the larger the difference in latency between shifting gaze away from target (for target-initial trials) and towards target (distractor-initial trials; r (25) = -.49, p =.014). This indicates that infants with a larger familiarity effect at 10 months were the ones who displayed better word recognition skill at 16 months: they fixated the correct object longer for target-initial trials, yet shifted gaze faster at distractor-initial trials.

To examine the relationship between accuracy and speed of known word recognition at 16 months and speech segmentation at 10 months, we disentangled the measure of delta LS, by calculating the latency to shift to other object separately for target-initial and for distracter-initial trials. The duration of fixating the correct object before eye gaze is switched away to distractor (i.e., accuracy) is related to previous speech segmentation brain correlates (r(25) = -.55, p =.004), indicating that the longer infants continued to look at the correct object at 16 months, the larger their familiarity effect at 10 months. The latency to switch towards target at 16 months, which reflects speed of word recognition, is not related to speech segmentation skill at 10 months (r(25) = +.017, p =.94).

The delta PTL provides a further measure of known word recognition, namely a relative increase in total looking time at target in a 2500 ms time window from onset of critical word. This static measure of accuracy was neither related to concurrent real-time measures of speech processing nor to segmentation ability. As Table 4.3 further shows, the CDI scores at 10 and 16 months were also not related to any other language variable obtained.

In sum, the ability to recognize words in continuous speech at 10 months is related to a real-time, objective, measure of accurate word recognition at 16 months: the larger the familiarity effect, the longer infants continue to fixate the correct object upon hearing its matching label. No such relationship was observed with a static measure of word recognition or with subjective measures of receptive vocabulary size.

Table 4.3: *(Pearson) correlation coefficient matrix for speech segmentation ability at 10 months, and subsequent recognition of known words at 16 months, and other obtained language measures, with in brackets the number of participants involved in the comparison. The ERP correlates of speech segmentation ability are calculated by subtracting the mean amplitude of ERPs for familiarized-unfamiliarized words over frontal electrodes, with the more negative, the larger the effect of familiarity. For each measure the mean and range are given.*

Measure	Age	1.	2.	3.	4.	5.	6.
0. Segmentation ability (-3.5μV; [-19.8 - +8.7])	10 months	-.49* (25)	-.55** (25)	+.017 (25)	+.193 (25)	-.092 (27)	+.021 (27)
1. delta LS (105 ms; [-516 - +823])	16 months		+.64*** (25)	-.57** (25)	+.040 (25)	-0.52 (24)	-.22 (25)
2. LS away from target (3518 ms; [2856 – 4080])	16 months			+.26 (25)	-.15 (25)	+.019 (24)	-.21 (25)
3. LS towards target (3412 ms; [2720 - 3896])	16 months				-.21 (25)	+.087 (24)	+.050 (25)
4. delta PTL (7.8%; [-10.2 - +27.1])	16 months					+.082 (24)	+.20 (25)
5. CDI – items understood (68 items; [1 - 352])	10 months						+.81*** (26)
6. CDI – items understood (203 items; [35 - 463])	16 months						

Note * $p<.05$; ** $p<.01$, *** $p<.001$, *LS = latency to shift to other object after naming at 2500 ms; delta PTL = added proportional looking at target in post-naming phase, relative to pre-naming phase.*

DISCUSSION

The goal of Experiment 4.2 was to examine how infants' ability to recognize word forms at 10 months was related to their ability to recognize word meaning at 16 months. Previous research has shown that performance in speech segmentation task is related to subsequent language development. We therefore hypothesized that performance in Experiment 4.1 should be related to performance on another language task, as long as the latter was a valid measure of current language development. One such objective measure can be obtained in a looking-while-listening task, which examines infants' looking behaviours in real-time in reaction to speech. In our version of the LWL task, there were several commonalities with Experiment 4.1. First, across tasks, target words were presented in continuous speech, making speech segmentation a necessary step for successful word recognition. Second, for both tasks we obtained objective individual measures of word recognition in real-time.

In Experiment 4.2, we assessed both known and novel word processing skills in infants six months after Experiment 4.1, with performance on known trials hypothesized to be a more reliable indicator of current language status than performance on novel trials. In this follow-up experiment the same infants as in Experiment 4.1, now 16 months old, showed evidence of recognizing known words in the task: they looked longer at the correct object after than before hearing its name.

The major finding of this experiment is that we observed a relationship between a physiological effect of word form recognition in Experiment 4.1 and a behavioural effect of word meaning recognition in Experiment 4.2: The larger the infants' ERP correlates for word form recognition in Experiment 4.1, the longer the infants fixated the correct object when they already looked at this upon naming, six months later.

On the other hand, the CDI scores in this study, generally used to assess concurrent language profiles, were questionable, because they did not correlate with any other obtained language scores, and they were not normally distributed, taken from a small sample size. Giving a reliable indication of infants' receptive language skill can be difficult; this was exactly why we carried out Experiment 4.2.

Besides assessing known word processing skill, we also aimed to examine infants' ability to learn a novel word and subsequently map it correctly to a novel object. However, although the task at sixteen months was suitable for examining individual variability in known word processing, the results from the task for novel word learning skill did not allow us to subsequently investigate the link between between this skill and earlier obtained ERP results, because the 16-month-olds as a group did not show ay evidence of having learned the novel mapping. There are several possible reasons why the infants did not learn this mapping. For instance, they might have been too young to learn this presumably difficult task under the given circumstances at which we trained the novel word-to-object mapping. Another possibility is that the simultaneous presence of the unlabeled object in the play phase might have hindered the correct mapping, because infants could then have extended the label to the unnamed object (Plunkett, Hu & Cohen, 2008). Nevertheless, regardless of the possible reasons that could explain this lack of learning, the aim of Experiment 4.2 was not to study novel word learning in itself (as it was in Experiment 4.1), but to obtain an objective and valid measure of word meaning recognition in continuous speech, which in turn could then be linked to other measures of language development.

To summarize, infants who at 10 months showed a larger familiarity effect for words in continuous speech were also more accurate in their looking behaviour at 16 months. Together, this suggests that the size of an electrophysiological response indexing word segmentation skill can be a reliable predictor of language development.

CONCLUSION

In Experiment 4.1 we assessed whether 10-month-olds can build up a memory trace for words they had to segment from continuous speech, and recognize them as familiar in subsequent utterances, again by segmenting them from speech. By using the on-line measure of ERPs, we demonstrated that infants can achieve this: For both the familiarization and the test phase, the infants elicited a word familiarity effect. When we compared the manifestations of this effect in this study, the earlier onset and more focal distribution of the word familiarity effect in the test phase suggested that there was an increased ease of word recognition at test, relative to the situation of word recognition in the familiarization phase.

In Experiment 4.2 we assessed how the same infants performed on an eye-tracking task measuring their skill to recognize word meanings at 16 months. Hence, both experiments provided on-line measures of word recognition in continuous speech, yet whereas the first only involved word form recognition (i.e. distinguishing familiarized versus unfamiliarized words), the second examined the result of word recognition, (i.e. the subsequently mapping of word form to an object). ERP correlates in Experiment 4.1 were related to behavioural performance in Experiment 4.2: the larger the familiarity effect, the longer infants continued to look at the named known object. This demonstrates that the ability to segment words from speech is related to subsequent successful word recognition in continuous speech. The observed link further underscores the importance of speech segmentation skill for word recognition, whether it concerns word forms at 10 months or word meaning at 16 months.

BRAIN POTENTIALS FOR WORD SEGMENTATIO SEGMENTATION PREDICT LATER LANGUAGE DEVELOPMENT

CHAPTER 5

This chapter is a slightly revised version of Junge, C.M.M., Hagoort, P., Kooijman, V.K. & 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* (pp.209 -220). Somerville, MA: Cascadilla Press.

ABSTRACT

Since infants mainly hear multi-word utterances, with no reliable pauses between words, segmenting words from speech is vital for later language development. Kooijman (2007) used ERPs to study infants' ability to recognize words in fluent speech. She tested Dutch ten- and seven-month-olds. The older age group showed a negative ERP effect of familiarity, but the younger age group did not. To test whether this interindividual variability in the ERP responses at seven months was related to later language skills, 82% of the same infants returned to participate in standardized language tests at three years. Infants with an ERP effect similar to the 10-month-olds had higher language quotients, compared to infants who followed the overall group pattern. Thus, ERP measures of segmentation at an age as young as seven months predict later language profiles at three years. This relationship appears at an individual level, even though the group performance was different from that of the 10-month-olds.

INTRODUCTION

A lexicon maps words to concepts. For infants starting to acquire a lexicon, successfully mapping between word and concept requires not only being able to identify the concept, but crucially, also being able to identify the word (Waxman & Lidz, 2006). This is not as easy as it seems, since infants mainly hear multi-word utterances (Morgan, 1996; Van de Weijer, 1998; Woodward & Aslin, 1990), with pauses in the speech signal not corresponding reliably to word onsets. Hence, the ability to segment words from speech is vital for vocabulary acquisition.

Most of the cues that listeners can exploit to segment speech are learned through native language experience (Cutler, 2002). These cues are probabilistic rather than fully reliable; no single cue is sufficient to detect word boundaries. As Jusczyk, Houston & Newsome (1999) showed, an important cue for infants learning stress-based languages is that a stressed syllable signals word onset for a majority of words (Cutler & Carter, 1987, for English; Schreuder & Baayen, 1994; for Dutch). Infants who are 7.5 months old can recognize infrequent strong-weak words such as *hamlet*, but only by 10.5 months can they recognize infrequent words with the opposite, weak-strong pattern, such as *guitar*. Other language-specific cues that infants can use are the phonetic and phonotactic regularities in the native language (e.g., Mattys, Jusczyk, Luce & Morgan, 1999).

Newman, Bernstein Ratner, Jusczyk, Jusczyk & Dow (2006) have recently demonstrated that performance on speech segmentation tasks, but not on tasks measuring language discrimination or prosodic preferences, is related to expressive vocabulary at 24 months. Infants who, between 7.5 and 12 months, conformed to the overall group performance in language-segmentation studies had a larger expressive vocabulary later, compared to infants who did not produce this pattern. This difference in language achievement was still visible when these children were between four and six years old: performance on standardized language tests was significantly higher for 'segmenters', though the groups did not differ in overall intelligence quotients. Other evidence comes from a study (Graf-Estes, Evans, Alibali & Saffran, 2007) in which 17-month-old infants were first familiarized with an artificial language stream, and then taught a novel word. This novel word was either a whole word or part-word from the language stream. Infants showed only signs of subsequent word recognition when this novel word was a whole word but not when it was a part-word, demonstrating that the ability to segment words from speech is central to making a successful word-concept mapping.

Jusczyk and Aslin (1995) were the first to use the headturn-preference procedure to study word segmentation in infants, by modifying the original paradigm (Fernald, 1985) into a familiarization period followed by a test phase. After hearing highly frequent words several times in isolation (familiarization period), 7.5-month-olds attend in the test phase longer to passages containing these words, compared to passages containing unfamiliarized words.

However, it is also possible to study infants' ability to recognize words in running speech by recording event-related brain potentials (ERPs). This electrophysiological measure has the advantage of providing an online measure of word segmentation. Also, it is a more direct measure, since infants are not required to make any overt behavioral response. As Aslin & Fiser (2005) noted, it is difficult to interpret null results in behavioral infant studies, because there is always the possibility that infants fail to show a preference for one situation above the other, yet are able to distinguish between the two situations. Kooijman, Hagoort & Cutler (2005) were the first to develop an ERP analogue of Jusczyk et al.(1999)'s study. They tested Dutch infants first at ten months, an age at which they behaviorally have been shown to segment trochaic words from speech (Kuijpers, Coolen, Houston & Cutler, 1998). Infants heard a maximum of 20 familiarization and test phase blocks. Per block, infants first heard a low-frequent trochaic word such as *hommel* ('bumblebee') ten times in isolation, followed by eight sentences in random order, half containing the familiarized word in mid-sentence position, half containing a similar low-frequency word, such as *viking* ('Viking'). See Table 5.1 for an example of a block. The ten isolated words resemble the familiarization phase, and the eight sentences resemble the test phase of Jusczyk et al.(1999)'s first experiment. Event-related potentials were subsequently calculated by averaging over the familiarized words in sentences and over the unfamiliar words (with a minimum of ten trials per subject average per condition). There was a difference between the two conditions in the time window 350 – 500ms post word onset: familiar words were processed more negatively on left-frontal electrodes, indicating that the infants recognized the familiarized words. This negative effect of word familiarity appears to be quite stable for this age group. We see a similar negative effect of word familiarity in several 10-month-old word-segmentation studies in our lab (Junge, Cutler & Hagoort, submitted (Chapter 4, this thesis); Junge, Kooijman, Hagoort & Cutler, submitted (Chapter 3, this thesis); Kooijman, Hagoort & Cutler, 2009), as well as in French 12-month-olds (Goyt & Nazi, 2008).

Table 5.1: Example of an experimental block from Kooijman et al. (2005).

Familiarization: Ten repetitions of *hommel* (bumblebee) in isolation

Test:

De hommel vliegt van bloem tot bloem	The bumblebee flies from flower to flower
Het is een oude hommel met gele strepen	It is an old bumblebee with yellow stripes
Een viking reist naar verre landen	A Viking travels to places far away
Die kleine viking is niet sterk maar slim	That small Viking is not strong, but smart
Een kleine hommel zit op het gordijn	A small bumblebee is sitting on the curtain
Dat is de andere viking met veel vijanden	That is the other Viking with many enemies
Vaak kan een hommel erg hard zoemen	Often a bumblebee can buzz very loudly
Pieter zag die viking uit het Noorden	Pieter saw this Viking from the North

Kooijman and colleagues also used this design to look at Dutch 7-month-olds, an age group for which there is no behavioral evidence that they are able to segment words from speech (Kooijman, 2007; Kooijman, Johnson & Cutler, 2008). With ERPs, they found that 7-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 7-month-olds showed a positive effect of familiarity, most prominent on four right-frontal electrodes. Figure 5.1 illustrates the differences between the two age groups. The time window of the effect was slightly smaller, but again around 400 ms. This shows that 7-month-olds are able to recognize words from speech, although the underlying brain response differs from that of their older peers. There were some 7-month-olds, however, who showed a pattern similar to that of 10-month-olds.

Given that the ability to segment words from continuous speech is essential for language development, what does it mean that some 7-month-olds show this pattern, and others have a different pattern? Is this variability in ERP responses for word recognition related to later language development? In other words, is there a relationship between word segmentation ability and later language scores similar to that observed by Newman et al. (2006)? The measure of speech segmentation ability in the present study differs from that of Newman et al.'s (2006) study in several respects: our infants are as young as seven months, they have Dutch as their native language, and they were tested with ERPs rather than with behavioral methods. We obtained language quotients when these children were three years old to see if infants with a similar ERP pattern as their older peers differed in their later language profiles from the children who followed the overall 7-month-old pattern.

Several studies have investigated the relationship between language-related ERPs in infants and later language development (e.g. Friedrich & Friederici, 2006; Rivera-Gaxiola, Klarman, Garcia-Sierra, & Kuhl, 2005) or between infants with or without a familial risk of language impairments (e.g., Friedrich, Weber & Friederici, 2004;

Torkildsen, Syversen, Gram Simonsen, Moen & Lindgren, 2007). Rivera-Gaxiola et al. (2005), for instance, used the mismatch negativity (MMN) paradigm to study native and non-native speech contrasts in typically developing 11-month-olds. For the non-native speech contrast, there was no overall group MMN effect. However, by looking at the individuals' ERP waves, there were two possible types that together were averaged out. Infants who showed a similar ERP for the non-native speech contrast as for the native contrast displayed smaller vocabularies at 18-30 months than infants who showed an ERP effect that differed in polarity for the non-native speech contrast. Together, these studies show that data from electrophysiological studies are suitable for measuring the relationship with later language development.

In the present study we explore the relationship between infants' ERPs for word segmentation at seven months and later language profiles at three years. We split the infants into two groups, depending on the average polarity on left-frontal electrodes in the 350 – 450 ms time window at seven months: Negative responders (whose individual ERP effect of familiarity resembled that of 10-month-olds) and Positive responders (whose individual effect resembled that of the overall 7-month-olds). The smaller plots in Figure 5.1 demonstrate this. We hypothesize that those infants with similar ERPs as the 10-month-olds will reveal higher language scores.

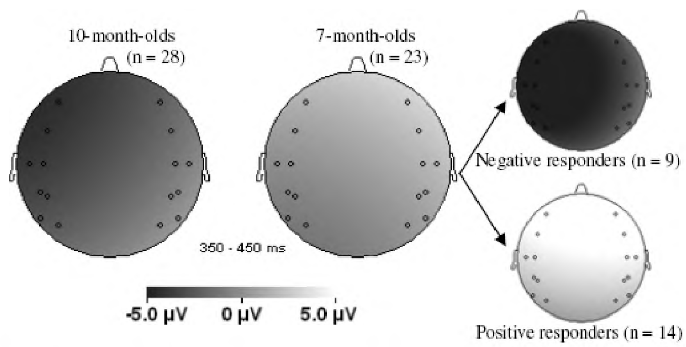

Figure 5.1: *Mean distribution plots for the ERP effect of familiarity (familiar – unfamiliar words) in the 350–450 ms time window for 10- and 7-month-olds. The two smaller plots divide the 7-month-olds into the two subgroups.*

METHOD

Participants

Twenty-eight monolingual 7-month-old infants (14 girls), who were full-term (± 14 days from due date) from families with no history of language or neurological impairments, participated in the original ERP experiment on word segmentation. The majority of infants came from middle-class, college-educated parents. Twenty-three (11 girls) children returned for testing, a return rate of 82%. Two infants could no longer be reached and (parents of) three infants did not want to participate. The 23 children (all right-handed) were on average 36.3 months old (range 28.4 – 46.6 months)[1]. We subsequently divided the children into two groups, based on the polarity of the individual ERP effect of familiarity on left-frontal electrodes (where the effect for 10-month-olds was present): those who resembled the 10-month-olds

[1] At return, infants differed widely in their age. This is because it took a long time to find enough seven-month-olds. It motivated us to use standardized language tests, which controlled for the factor age (and which, as it turned out, also allowed us to test the five-year-olds in Chapter 6 with the same procedure).

("Negative responders"), and those who did not ("Positive responders"). Figure 5.1 shows that of these 23 children, 9 children (3 girls) fell into the Negative responders group, and 14 children into the Positive responders group. They do not differ in number of trials per condition: Positive responders have on average 21 trials per condition per subject, and Negative responders 20 trials (t (21) = 0.551, p = .59; t (21) = 0.099, p = .92 for familiar and unfamiliar words, respectively). They also did not differ in age during any of the tests (for the ERP experiment, Positive and Negative responders have a mean age of 217 and 218 days, (t (21) = -0.213, p = .83); for the follow-up study, 37.6 and 34.4 months, respectively (t (21) = 1.307, p = .21)). There were two Positive responders with a history of speech therapy.

Procedure and Materials

All children participated in two norm-referenced language tests, the "Reynell Test voor Taalbegrip" (van Eldik, Schlichting, Lutje Spelberg, van der Meulen & van der Meulen, 1995), measuring receptive language development, and the "Schlichting Test voor Taalproductie" (Schlichting, van Eldik, Lutje Spelberg, van der Meulen & van der Meulen, 1995), measuring productive language development. Together, the tests are a slightly modified translation of the Reynell Developmental Language Scales (Reynell, 1985) into Dutch. They are the established tests used in the Netherlands for measuring language development problems, and are norm-referenced over 1,000 normally developing children. The test results for each child are converted into language quotients (LQs), depending on the age of the child in months. These scores have a mean of 100 and a standard deviation of 15 points. A child is considered to have a risk of language impairment at an LQ below 85. Both tests distinguish between levels of difficulty, allowing older children to start at a more advanced level, and both are suitable for children between two and six years.

The children were individually tested by the first author, blinded to their earlier laboratory profiles. In the first session they participated in the "Reynell Test voor

Taalbegrip", measuring their LQs for comprehension. Here, they had to act out or point to requested objects. In the second session, which took place on average 8 days (range 1- 21 days) after the first session, they participated in two subtests of the "Schlichting test voor Taalproductie": the "Test voor Zinsontwikkeling", measuring LQs for sentence production, and the "Test voor Woordontwikkeling", measuring LQs for word production (i.e., expressive vocabulary development). In the first subtest, children are required to make sentences of a similar structure as the experimenter does on the basis of certain pictures or arrays of toys. In the second subtest children have to name things in pictures or finish the experimenter's sentences describing the pictures. In addition to both tests, parents were asked to complete a Dutch version of the "Speech and Language Assessment Scale" (Hadley & Rice, 1993), in which they had to rate their child's development on a variety of language skills compared to 'other children of the same age', starting from 1 ('very poor') to 7 ('very good'). See Appendix 1E for the Dutch version (translated by first author).

RESULTS

At seven months: Ability to segment words

To ensure that the subset of the 23 children who returned for follow-up testing was representative of the larger sample, we first repeated the analyses from Kooijman (2007). We performed repeated measures analyses of variance (ANOVAs) on the mean amplitudes in the selected time windows, with Familiarity (familiar vs., unfamiliar), Quadrants (4: left frontal, right frontal, left posterior, and right posterior), and Electrode (5; left frontal: F7, F3, FT7, FC3, C3; right frontal: F8, F4, FT8, FC3, C4; left posterior: LT, LTP, CP3, LP, P3; right posterior: RT, RTP, CP4, RP, P4) as variables. For all tests, we used the Huynh-Feldt epsilon correction, and report the original degrees of freedom and adjusted p-values. For the same time window (350 – 450 ms), we see again that although there was no main effect of Familiarity, the interaction between Familiarity and Quadrant was significant ($F(1, 22) = 0.86$, $p =$

.364; F (3,66) = 5.17, p = .005, respectively). The distribution of the familiarity effect is similar to the original study, although it is now significant over the whole right-frontal quadrant (F(1,22) = 4.355, p = .049). See also Supporting Table 1 from Appendix 3D.

Having now established that the subset of children is representative of the full sample, we then tested whether, besides a difference in distribution and polarity, the Positive & Negative responders differed in the onset of the familiarity effect. Both groups have similar onset effects, with for Positive responders the effect starting at 100ms for right electrodes FT8 and RT, and for Negative responders starting at 110ms for left electrodes FT7 and LT. Both groups also do not differ in the familiarization period: a comparison of the ERPs for the first two versus the last two tokens of isolated words in the time window 200-500ms show again a main effect of Repetition ($F_{,21}$ = 5. 132, p =0.34), but no interaction of Repetition x Group ($F_{1,21}$ = .001; p = .973), similar to that of the 10-month-olds. See also Supporting Table 2 from Appendix 3D.

Relation between ability to segment words at seven months and later language development at three years

Results for the follow-up standardized language tests show that all children achieved scores within or above the normal range. Overall, children have high LQs for comprehension (m = 115.4, sd = 11.8), for sentence production (m = 113.9, sd = 14.7), and for word production (m = 118.9, sd = 11.2). Their parents rate their average language skills also as somewhat better than peers (m = 4.7, sd =0.9). These scores correlate highly with each other, as illustrated in Table 5.2.

Table 5.2: *Correlation coefficients relating the language quotients and parental questionnaires at three years (***p <.001 **p < .01 *p < .05).*

	Sentence production LQ	Word production LQ	SLAS average
Comprehension LQ	.577**	.515*	.499*
Sentence production LQ	-	.411	.669***
Word production LQ	-	-	.326

Figure 5.2 shows that the children who already at seven months have similar ERPs as 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). The Negative Responders perform on average at 1.5 standard deviations above the LQ mean.

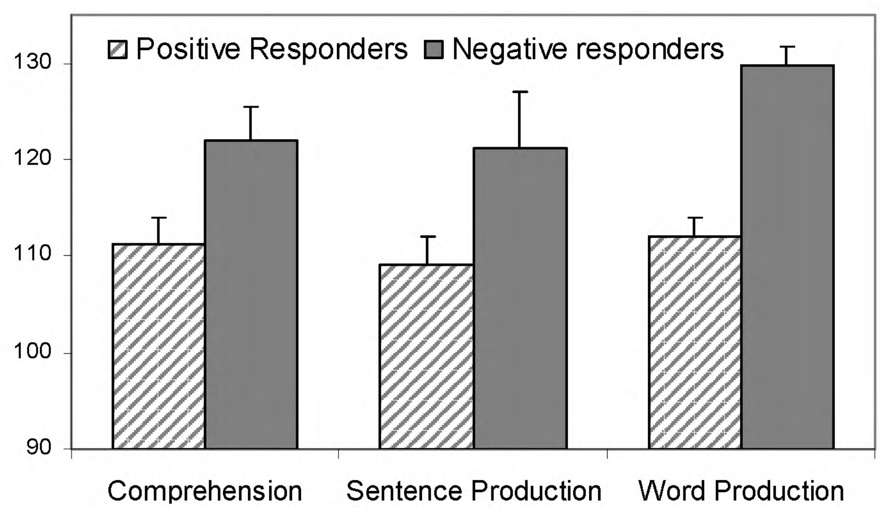

Figure 5.2: *The three language quotients at three years split by group performances at seven months (***p <.001 **p <.05 *p <.10; error bars are one standard error from the mean).*

Further, across all 23 subjects, Figure 5.3 shows a significant correlation between the ERP effect 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 ($r_{bivariate}$ = -.45, p = .02; with LQs for comprehension and sentence production partialled out, $r_{partial}$ = -.42, p = .06). To assess the relative contribution of later language scores at three years and word segmentation at seven months, we used a discriminant function analysis with step-wise selection and a predictor inclusion criterion of p = .05, and the predictor variables of LQs for comprehension, sentence production, word production as well as the overall SLAS scores. Only the LQ for word production, indicative of expressive vocabulary skill, was significantly related to early segmentation ability, predicting correctly the segmentation ability for 21 of the 23 children.

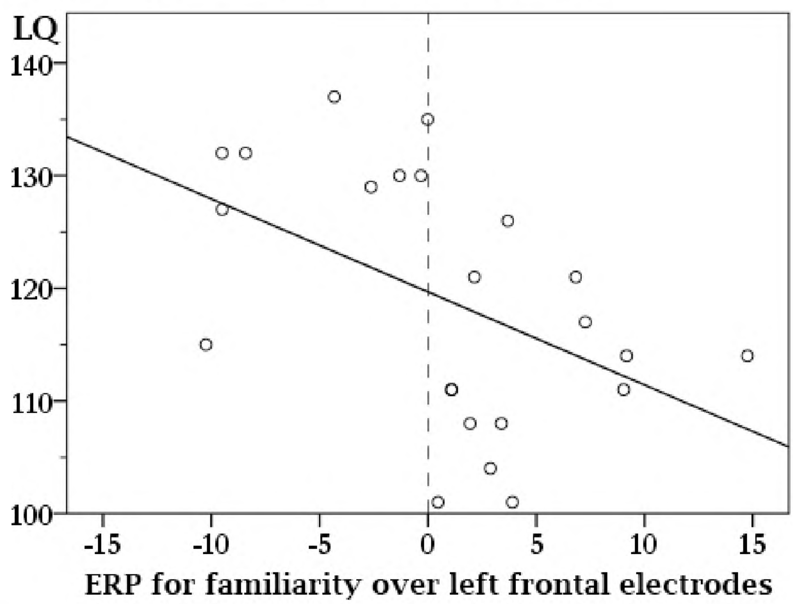

Figure 5.3: *The more negative the difference wave between familiarized and unfamiliar words at seven months in the 350 – 450 ms time window, the higher the LQ for word production at three years. The dotted line indicates the split between Negative and Positive responders.*

Parents of Negative responders rated their children higher than parents of Positive responders did for their children (t_{21}= 1.86, p = .077). Figure 5.4 illustrates that the Negative responders receive higher ratings on all subscales of the SLAS. The groups differ at beyond p .05 on the syntax and talkativeness subscales (t_{21}= 2.09, p = .049, and t_{21}= 2.58, p = .018, respectively), and at beyond p .10 on the articulation subscale (t_{21}= 1.82, p =.084).

Together, these results show that ERPs for word recognition in continuous speech at seven months are an indication of later language development. Negative responders have higher language scores than Positive responders. This is most prominent for expressive vocabulary scores at three years.

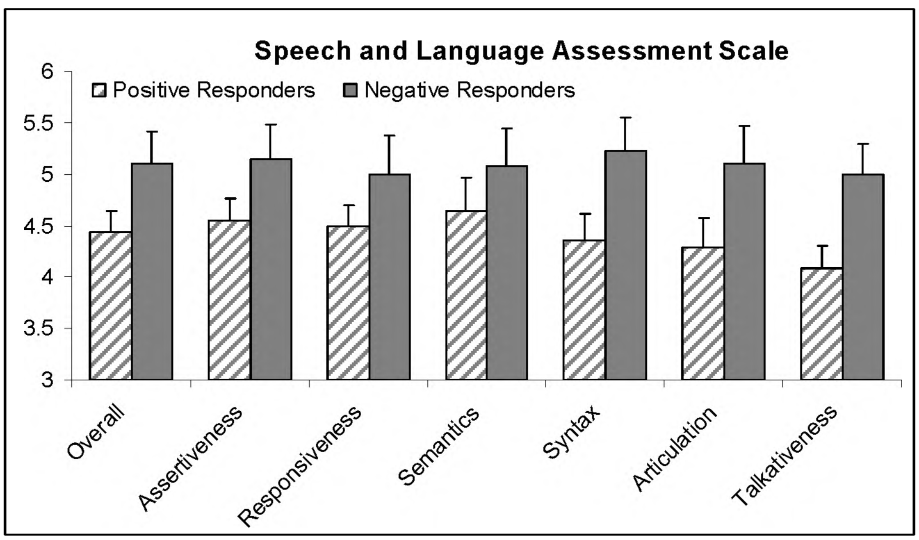

Figure 5.4: *Group ratings on the SLAS: overall and per subscale, for the Positive and Negative Responders. A score of '4' corresponds to parents rating their child's language performance as equal to their child's peers; higher scores reflect better language ratings. Error bars are one standard error from the mean.*

DISCUSSION & CONCLUSION

By comparing the individual ERP responses of 7-month-olds to the 10-month-old ERP data on word segmentation, we see that 7-month-old infants with an effect of familiarity similar in distribution and polarity to the one for the 10-month-old overall group have higher later language scores than the remaining 7-month-olds. The differences of the ERP effect of familiarity between the Positive and Negative responders suggest that both groups use different underlying neural sources to achieve word recognition in continuous speech. Kooijman (2007) points out that this difference in polarity and distribution between the two age groups could also be the result of the rapid changes of infant brain maturation that take place between seven and ten months, such as the slow closing of the fontanels and increased dendritic growth and pruning. Within the same age group, however, this argument does not hold: the Positive and Negative responders are virtually matched in age. Moreover, the finding that both subgroups do not differ in the familiarization period suggests that here they use similar generators, demonstrating that it is not a case of the brain being more matured for Negative responders than for Positive responders, or vice versa.

When we further look at other infant ERP studies contrasting different ages, the observed effects appear to be quite stable over different ages, showing that with age there is only a trend going from a widely distributed effect towards a smaller, localized effect. This holds both for studies on known-unknown word processing (Mills, Coffey-Corina & Neville, 1997) as well as for studies on picture-word processing (Friedrich & Friederici, 2005; Mills, Conboy & Paton, 2005). For known-unknown word processing, this difference in distribution does not appear to stem from brain maturation, but from amount of language experience (Conboy & Mills, 2006; Mills, Plunkett, Prat & Schafer, 2005). Hence, it seems plausible that Positive and Negative responders use different neural generators to achieve the same result, which points to a difference in mechanisms used for recognizing words in running speech.

The question then turns to how one can explain this difference in use of mechanisms. Both prenatal (parental genetics, mother's general health and gestation period) and postnatal (family's socioeconomic status, parental education) factors have been identified among the influences that may alter the course of language development. Our subgroups do not differ, as far as we know, in these respects. One possible explanation, however, comes from Kuhl's "native language magnet theory-expanded" (NLM-e) model (Kuhl, Conboy, Coffey-Corina, Padden, Rivera-Gaxiola & Nelson, 2008). According to the NLM-e model, there is a critical period for infants, between six and twelve months, in which they develop neural networks specifically dedicated to native language processing, which in turn facilitates higher language learning. Infants who are more advanced in phonetic learning will also be more advanced in their next stage of language learning, that is, detection of word-like units. It is possible that the Positive responders are less advanced in their phonetic learning, thereby processing the continuous speech stream in a different manner than the Negative responders do. When it comes to the easier task of recognizing words in isolation, however, Positive responders use the same mechanisms as Negative responders.

Our results cannot distinguish between speech segmentation skill as special or as bootstrapped from a more advanced mechanism of native speech processing. We have only records of later language profiles to demonstrate the importance of speech segmentation ability, no concurrent language scores at seven months. In fact, measuring language development at seven months is impossible, since the widely-used parental questionnaires are only standardized from eight months old (Fenson, Dale, Reznick, Bates, Hartung, Pethick & Reilly, 1993). In either case, it makes sense to assume that speech segmentation ability is an important precursor for later language development, because it is crucial for building a vocabulary. This study shows that a left frontal negative amplitude for word familiarity as early as seven months is associated with later language profiles at three years. Other studies in our lab also link this negativity for word familiarity in continuous speech to future language development (Junge et al., submitted; Junge et al., submitted (Chapters 3 and 4, this thesis, respectively).

Studies on isolated word processing, comparing familiar/known versus unfamiliar/unknown word processing, also report similar negative ERP effects, just as we have seen in our word segmentation studies (Thierry, Vihman, & Roberts, 2003; Mills et al., 1997). It is likely that for infants with a very limited vocabulary, the same mechanism is involved for word recognition in continuous speech as for known versus unknown word processing. Although Mills, Plunkett et al., (2005) showed that for 20-month-olds it is word meaning rather than word form familiarity that explains effects of familiarity, it is likely that the recognition mechanism has evolved from one that at a younger age is mainly sensitive to word form repetitions. It is also possible that the observed negativity does not index word repetition, but rather word learning.

Research from adult studies on artificial language streams also shows a fronto-central negativity related to word repetition, which is explained as the on-line creation of a linguistic word-like representation (Cunillera, Toro, Sebastián-Gallés, & Rodríguez-Fornells, 2006). This contrasts, however, with the finding that word repetition in normal speech in adults is generally associated with a more positive amplitude, both for native and non-native speakers (e.g., Rugg, 1985; Snijders, Kooijman, Hagoort & Cutler, 2007). Even so, word form familiarity and online word learning are themselves likely to be related. What is clear is that a negative effect of word familiarity on left-frontal electrodes around 400 ms is related to later language development.

Early speech segmentation skill as a pathway to later language: How far does the path stretch?

CHAPTER 6

This chapter is a slightly revised version of Junge, C.M.M., Hagoort, P., Kooijman, V.K. & Cutler, A. (submitted). Early speech segmentation skill as a pathway to later language: How far does the path stretch?

ABSTRACT

Infants' ability to recognize words in continuous speech is vital for building a vocabulary. The word familiarity effect (WFE), an electrophysiological index of speech segmentation ability with a negative polarity in 10-month-olds (Kooijman, Hagoort & Cutler, 2005), is linked to later language development to three years: Infants who display a significant WFE show accelerated development compared to infants who do not. To examine the extent of this advantage, we tested five-year-olds who as 10-month-old infants had participated in a WFE study. The relationship between WFE and linguistic performance was no longer observed, suggesting that although being able to segment speech encourages early vocabulary development, it does not convey a language processing advantage into the school-going years.

INTRODUCTION

The speech infants hear, in their first year before they themselves begin to speak, consists mainly of multi-word utterances, without clear pauses between words (Morgan, 1996; Van de Weijer, 1998; Woodward & Aslin, 1990). Thus to construct an initial vocabulary and begin speaking themselves, infants must learn how to segment words from speech. An important and now repeatedly replicated finding is that the ability to accomplish such speech segmentation is positively correlated with linguistic performance in the following years of childhood (Newman, Bernstein Ratner, Jusczyk, Jusczyk & Dow, 2006).

This correlation appears, inter alia, when infant speech segmentation skill is measured electrophysiologically. Kooijman, Hagoort & Cutler (2005) originated event-related potential (ERP) measurement for infant processing of familiarized versus unfamiliar words in continuous speech. Ten-month-olds showed a clear recognition response, indicating that they had segmented the speech signal. This word familiarity effect (WFE) has a negative polarity, is predominantly present on left frontal electrodes, and appears quite stable for this age group: similar effects appeared in other 10-month-old word-segmentation studies in our laboratory (Junge, Kooijman, Hagoort & Cutler, submitted a (Chapter 3 this thesis); Junge, Cutler & Hagoort, submitted b (Chapter 4, this thesis); Kooijman, Hagoort & Cutler, 2009), and in French and German 12-month-olds (Goyet, de Schonen & Nazzi, 2010; Männel & Friederici, 2010). The WFE's links to later language development have been demonstrated in several ways. First, the larger the WFE in 10-month-olds who heard a word once in an utterance, the more words the same infants understood at 12 and 24 months (Junge et al., submitted (a); Chapter 3, this thesis). Second, although younger infants generally show a familiarity effect with positive polarity (Dutch seven-month-olds: Kooijman, 2007; German six-month-olds: Männel & Friederici, 2010), seven-month-olds with a negative WFE on left frontal electrodes ('N-responders') displayed higher language scores at three years than their peers with a positive familiarity effect ('P-responders'; Junge, Hagoort, Kooijman & Cutler, 2010; Chapter 5, this thesis).

Though studies linking early perceptual skill to subsequent language development have mostly followed children till 24 or 30 months (e.g., Cristià & Seidl, 2011; Friedrich & Friederici, 2006; Rivera-Gaxiola, Klarman, Garcia-Sierra & Kuhl, 2005; Tsao, Liu & Kuhl, 2004), language development of course does not stop at age two. Differences between children at this stage could reflect differences in the pace of language learning, without necessarily reflecting its ultimate success. Consider that by four years, most 'late-talkers' have caught up with their peers, if not afflicted with speech or language impairments (Leonard, 1997; Rescorla & Lee, 2000).

Evidence from Newman et al.'s (2006) study suggests, however, that speech segmentation performance can foreshadow language ability up to five years, Their study showed that two-year-olds with extreme vocabulary sizes (the top and bottom 15% of a large cohort) had differed in segmentation ability as infants. When the same children were assessed at 56 months, both groups had language abilities in the normal range and did not differ in overall IQ; nonetheless, the current language scores, and language-skill ratings by parents, were higher for the children who as infants had shown evidence of segmentation than for those who had not.

The ERP measures are not based on extreme groups, but reveal individual WFE size to be related to later language performance (e.g. WFE at seven months and language scores at three years: Junge et al., 2010; Chapter 5 this thesis). It is therefore of great interest to see whether this more sensitive measure reveals a continuing relationship between infant segmentation performance and linguistic ability in older children. Accordingly we assessed the participants from the study in which the WFE was first observed at 10 months (Kooijman et al., 2005) with the same standardized language tasks and parental questionnaires as used in the seven-month/three-year comparison. At return, the original 10-month-olds were now around five years old. This group had not previously been post-tested, so there was no issue of familiarity with the tests. In the ERP task at 10 months, these infants had heard 10 tokens of isolated words, before a recognition response was measured by comparing ERPs to the familiarized versus to unfamiliar words in continuous speech. Table 6.1 gives an example of an experimental block. Across the familiarization phase, ERPs to the isolated words became gradually more negative. In the test phase, the 10-month-olds on average displayed a WFE (familiarized versus unfamiliar asymmetry) around 400 ms from word onset. The mean WFE was reversed in polarity for other infants tested at seven months (Kooijman, 2007; see Figure 6.1A).

Table 6.1. *Example of an experimental block from Kooijman et al. (2005): left, the Dutch sentences, and right, their English counterparts. Target words are underlined.*

Familiarization: Ten tokens of *hommel* (bumblebee) in isolation	
Test:	
De hommel vliegt van bloem tot bloem	The bumblebee flies from flower to flower
Het is een oude hommel met gele strepen	It is an old bumblebee with yellow stripes
Een viking reist naar verre landen	A Viking travels to places far away
Die kleine viking is niet sterk maar slim	That small Viking is not strong, but smart
Een kleine hommel zit op het gordijn	A small bumblebee is sitting on the curtain
Dat is de andere viking met veel vijanden	That is the other Viking with many enemies
Vaak kan een hommel erg hard zoemen	Often a bumblebee can buzz very loudly
Pieter zag die viking uit het Noorden	Pieter saw this Viking from the North

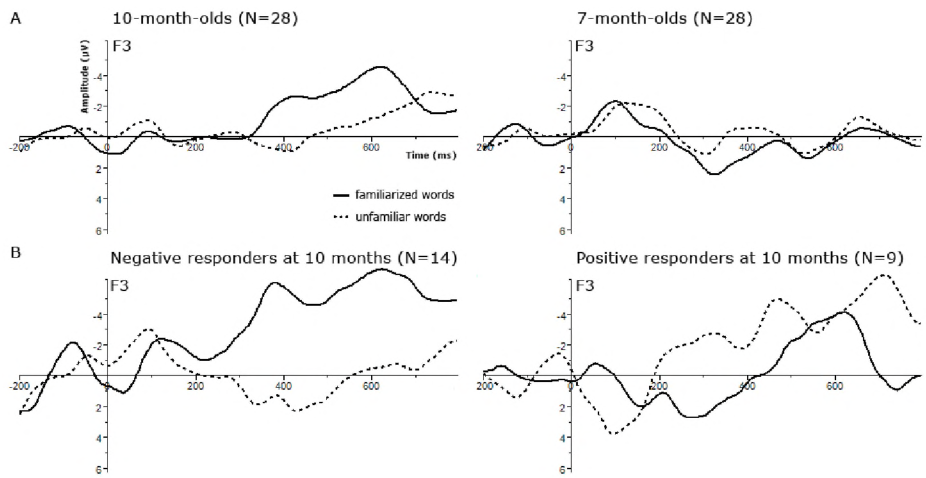

Figure 6.1A: *Grand average waveforms for the familiarized and unfamiliar words in continuous speech at left frontal electrode F3 for the two age groups tested. 0 ms indicates word onset; an additional 8Hz low-pass filter has been applied for illustrative purposes.* **Figure 6.1B:** *Grand average waveforms for the familiarized and unfamiliar words in continuous speech for the 10-month-olds who returned at five years, split into groups based on the voltage of the familiarity effect (familiarized – unfamiliar words) in the 350 – 500 ms time window for left frontal electrodes: Negative responders (i.e., who show a familiarity effect with negative polarity, typical for 10-month-olds) and Positive responders (i.e., who show a familiarity effect with positive polarity, typical for seven-month-olds).*

Comparison of individual performance in the ten-month-old group revealed that although most had shown the standard WFE (negative polarity), some participants had shown an effect with positive polarity, i.e., resembled their younger peers. Figure 6.1B shows the grand average waveforms for the former group (N–responders, conforming to the group-average response) versus those for the latter (P-responders, with individual effects resembling the average of Kooijman's (2007) seven-month-olds).

We first compared the WFE in the 10-month-old study to a separate processing measure at the same age. The building of a memory trace in the familiarization phase provides such a measure. We therefore compared groups created according to the average polarity on left frontal electrodes in the 350-500 ms time window in the test phase of the study (P- versus N-responders) on their performance across the familiarization with 10 tokens of the same word. A difference here would bolster the claim that infant speech segmentation skill is a sensitive measure for linguistic processing ability.

We then continued to asses the relationship between infant WFE and later language at five years in two ways. First, we examined this link prospectively, by comparing P- and N- responders on their language scores and parental ratings at five years. Generalization of Newman et al.'s (2006) finding to the individual level would predict that P-responders would have lower language quotients than their peers, and that parents of P-responders would rate their children's language abilities lower than parents of N-responders would do for their children.

In our second analysis, we assessed the link retrospectively, by creating groups based on the mean language quotients at five years. These groups were then compared on the distribution and latency of the WFE in the 10-month test phase. On the same prediction, infants with higher language quotients should have a more focal, but equally negative, WFE than infants with lower language quotients. This would further be in line with studies linking a familiarity effect restricted to left-temporal electrodes to advanced language skill (Conboy & Mills, 2006; Mills, Coffey-Corina & Neville, 1997; Mills, Plunkett, Prat & Schafer, 2005). A less scattered familiarity effect should reflect more efficient processing of words.

Should we, on the other hand, observe no relationship between infant WFE and language quotients at five years, our results could indicate a focal boost from speech segmentation skills to initial vocabulary construction, without long-term consequences for language development.

METHOD

Participants

Participants in Kooijman et al.'s (2005) study were twenty-eight monolingual Dutch-acquiring 10-month-olds (mean age 308 days, range 288-320 days, 11 girls). Twenty-three children (14 boys, 9 girls) were available for re-testing (a return rate of 82%, exactly as for the seven-month-olds re-tested by Junge et al. (2010). The 23 children were now on average age 62.5 months old (range 55 – 66 months, SD=3.7 months); none had history of seeing a speech therapist.

Procedure and EEG recordings at 10 months

Infants listened to at least nine blocks (maximum 20) of unique familiarization-and-test phases. They were awake and seated in a child seat, facing a computer screen in a sound-attenuating booth. Each 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.

Their EEG was continuously recorded at 200 Hz with infant-size Brain-Caps (cf. Kooijman et al, 2005; 2009), with 26 Ag/AgCl electrodes: 20 electrodes placed according to the 10/20 system (Fz, FCz, Cz, Pz, F7/8, F3/4, FT7/8, FC3/4, C3/4, CP3/4, P3/4 and PO7/8), and three pairs placed bilaterally on non-standard positions (a temporal pair LT/RT; a temporo-parietal pair LTP/RTP and a parietal pair

LP/RP).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. The signal was filtered off-line at 0.1-30 Hz. Individual trials with a baseline of 200 ms were screened for artifacts from 200 ms before to 800 ms after target word onset, and subject average waveforms for each condition calculated. For more information, see Kooijman et al. (2005): No pre-processing steps were altered from the original.

Procedure and materials at 5 years

All children undertook norm-referenced language tests (the same as used for re-testing the seven-month-olds; See also Appendix 1D). These tests are the Dutch equivalent of the Reynell Developmental Language Scales (Reynell, 1985). They are suitable for children between two and six years, and norm-referenced over 1,000 normally developing children. Each test distinguishes levels of difficulty, with older children starting at a more advanced level. The individual scores for each subtest are converted into language quotients (LQs), depending on the child's age in months, with a mean of 100 and a standard deviation of 15. Children with an LQ below 85 were considered to be at risk of language impairment.

The tasks were (1) "Reynell Test voor Taalbegrip" (van Eldik, Schlichting, Lutje Spelberg, van der Meulen, & van der Meulen, 1995), measuring language reception; (2) the "sentence production" test and (3) the "word production" test, both from the "Schlichting test voor Taalproductie" (Schlichting, van Eldik, Lutje Spelbroek, van der Meulen, & van der Meulen, 1995). Parents also completed the Dutch version of the "Speech and Language Assessment Scale" (SLAS; Hadley & Rice, 1993), in which they rated their child's development on a variety of language skills compared to 'other children of the same age', starting from 1 ('very poor') to 7 ('very good'). It has five composite scales: assertiveness; responsiveness; semantics; syntax; and articulation, as well as a separate scale for talkativeness (See also Appendix 1E).

Analyses

In the prospective analysis, we divided the five-year-olds based on the polarity of the individual word familiarity effect on left frontal electrodes at 10 months, for the time window in which the overall group pattern for the test phase was significant (350-500 ms). There were 14 N-responders (average familiarity effect is -8.1 µV, SD 6.7 µV; 8 boys), and nine P-responders (average familiarity effect +5.3 µV, SD 4.9 µV; 6 boys). The N-responders were 306.9 days old (SD 7.9) at the word segmentation task, and 63.6 months (SD 3.0) at return, the P-responders 306.2 days (SD 10.8), and 60.7 months (SD 4.1) respectively. The groups did not differ in age at 10 months ($t(21) < 1$, $p = .60$), although on return N-responders were on average three months older than P-responders ($t(21) = 2.01$, $p = .06$).

To examine whether these two groups differed in their familiarity response for the familiarization phase (words presented 10 times in isolation), we first replicated Kooijman et al.'s (2005) analyses of mean amplitudes for the first two ('unfamiliar') versus the last two tokens ('familiar') in this phase. Amplitude for the time window 200-500 ms from word onset was analyzed with repeated-measures ANOVAs, with the factors Familiarity (2) , Quadrant of the brain (4) and Electrode (5; left frontal: F7, F3, FT7, FC3, C3; right frontal: F8, F4, FT8, FC3, C4; left posterior: LT, LTP, CP3, LP, P3; right posterior: RT, RTP, CP4, RP, P4) as independent variables. For all tests, we used the Huynh-Feldt epsilon correction, and we report original degrees of freedom and adjusted p-values. To compare how often words must be heard before a recognition response appears, we also conducted for each group post-hoc comparisons with paired t-tests between the first two tokens and each subsequent pair of tokens. Last, we assessed whether the groups differ on language quotients or parental ratings of language abilities at five years.

In the retrospective analysis, we used language scores at five years to create two groups. The mean language quotient (averaged over LQs for comprehension, for sentence production and for word production) was 117.0 (SD 6.6). Children with higher language quotients (HLQ group; range 117.3 – 129.3; n=12; 6 boys) had a mean age of 61.6 months (SD 4.1), those with lower language quotients (LLQ group; range 105.3 – 116.3; n=11, 8 boys) a mean age of 63.4 months (SD 2.9). The group age difference was insignificant (p >.2). We then compared the WFE for each group in the 10-month-old test phase, where infants were required to segment sentences into words. ANOVAs were performed on mean amplitudes of the 350-500 ms as well as on 100 ms time windows from word onset, with familiarity (2), hemisphere (2), anterior/posterior (2) and electrode (5) as within-subjects factors, and Vocabulary Group as a between-subjects factor. Analyses were also repeated for each group separately.

RESULTS

At 10 months: Recognizing words in isolation

Kooijman et al. (2005) reported that the WFE for words heard in isolation became gradually more negative, over frontal electrodes, from 200 to 500 ms after word onset (N200-500). When split by the polarity of the familiarity effect in the test phase, P- and N-responders showed similar begin and end states of the familiarization phase ($F_{1,21}$ =0.23, p=.64; see Supporting Table 1, Appendix 3E). Post-hoc comparisons with paired T-tests, however, showed that the groups differed in the build-up of the memory trace across this phase. As Figure 6.2 demonstrates, for N-responders, the N200-500 was already significantly modulated by the third and fourth time a word was presented (t_{13}=2.52, p=.026), and continued to become more negative throughout the familiarization phase (t_{13}>2.20, p<.05; See also Supporting Tables 2a in Appendix 3E). In contrast, P-responders only showed modulation when words were presented for the ninth and tenth time (t_8= 2.39, p=.044; all other comparisons, t_8<1, p>.4; See Supporting Table 2b in Appendix 3E). (Note that these differences between N- and P-responders were also obtained across the full original sample of 28 infants; See also Supporting Tables 2a and 2b in appendix 3E, respectively.)

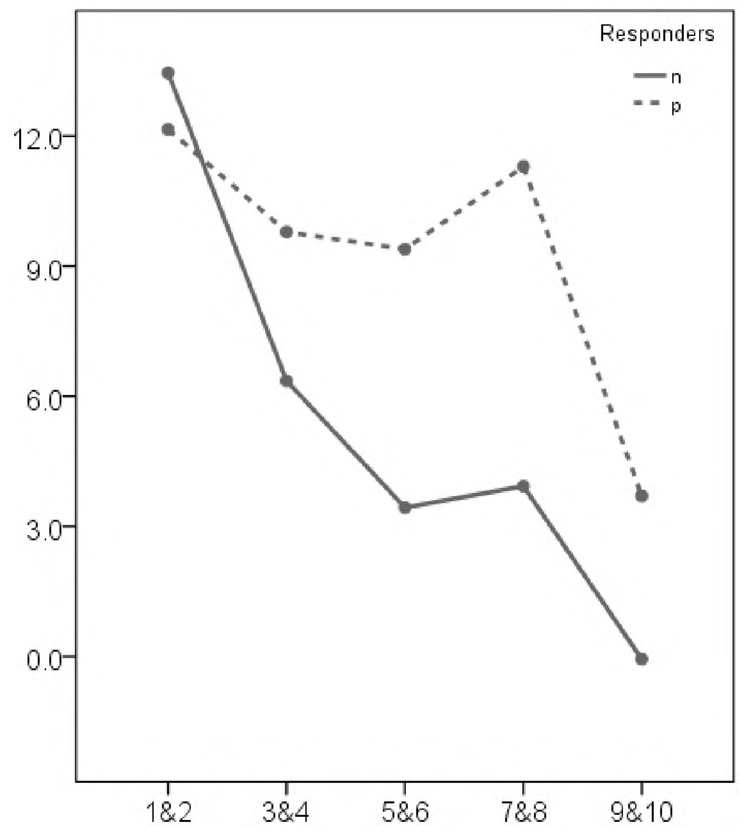

Figure 6.2: *Mean amplitude (µV) per word position in the familiarization phase (i.e. 1&2, 3&4, 5&6, 7&8, 9&10) from 200-500 ms over the frontal, fronto-temporal and fronto-central electrodes, separate for the P- and the N-responders.*

Language measures at five years

Results for the follow-up standardized language tests reveal that all children achieved scores within or above normal range. Overall, children have high LQs for comprehension (m=116.0, SD=8.2), for sentence production (m =117.5, SD = 8.6), and for word production (m=117.3, SD=9.0). Note, however, that the variation is less than in the overall population (i.e., sd=15). The SLAS average reflects that parents rated their children on average (5.2, SD=0.7) as slightly higher than their peers (corresponding to '4' on a seven-point Likert-type scale).

Later language profiles viewed prospectively

N-responders have slightly lower language quotients at five years than P-Responders (See Figure 6.3A). These differences, however, are not significant (comprehension: (t_{21}=1.36, p=.19); sentence production: (t_{21}=0.75, p=.46), or word production: (t_{21}=0.70, p=.49)). Hence, at five years the two groups have similar language profiles. Because N-Responders were on average three months older, and we see no relationship between age and raw scores (*Pearson's* R <+.19, p> .41), it could be that standardizing raw scores has a negative impact on performance. We thus also compared groups on raw scores (See Figure 6.3B). The P- versus N-responder differences are further attenuated (t_{21}<.6, p>.5; See Supporting Table 2A in Appendix 3E).

Moreover, the SLAS ratings from the parental questionnaires reveal no P- versus N-responder differences. As Figure 6.4 shows, parents of N-responders evaluated their offspring's language abilities on average as somewhat higher than did parents of P-responders for their children. Nevertheless, again no differences between the groups are significant (mean rating: t_{21}= -.30, p= .77; subscales (*t21*<-1.4, p >.17; See further Supporting Table 2B in Appendix 3E).

Together, these comparisons suggest that 10-month-old P- and N-responders do not differ in language abilities at five years.

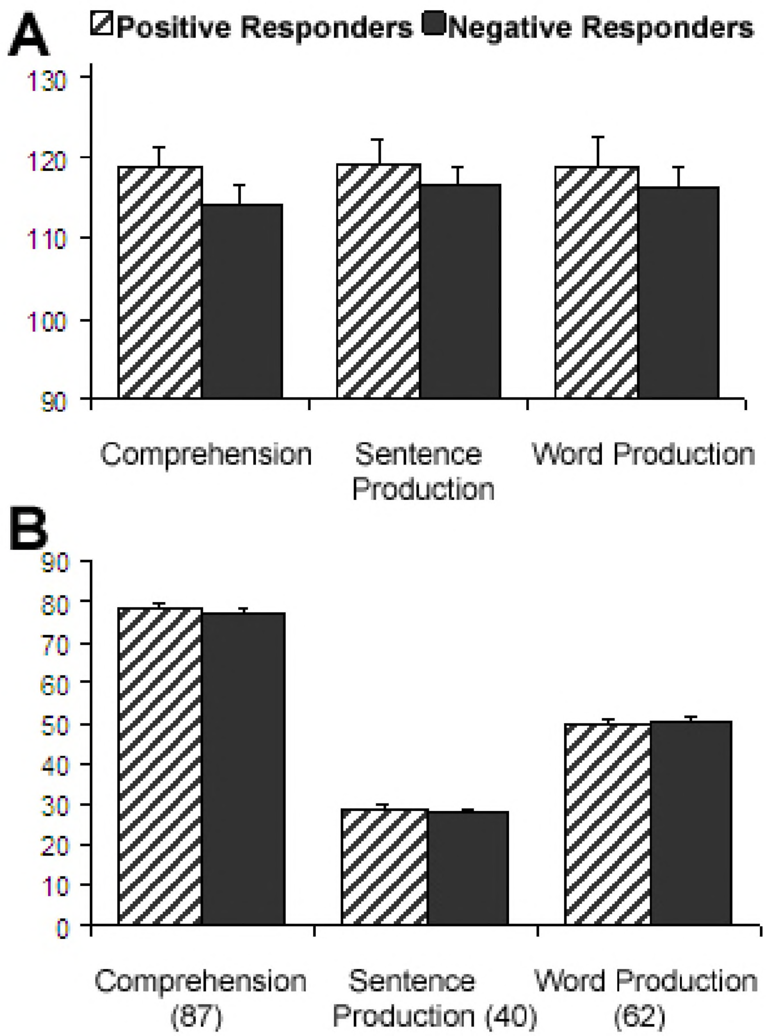

Figure 6.3: *Language performance at five years split by group performances at 10 months (error bars are one standard error from the mean):* **6.3A**, *with standardized language quotients on the Y-axis;* **6.3B**, *with raw language scores on the Y-axis (in parentheses the maximum possible score for each subtest).*

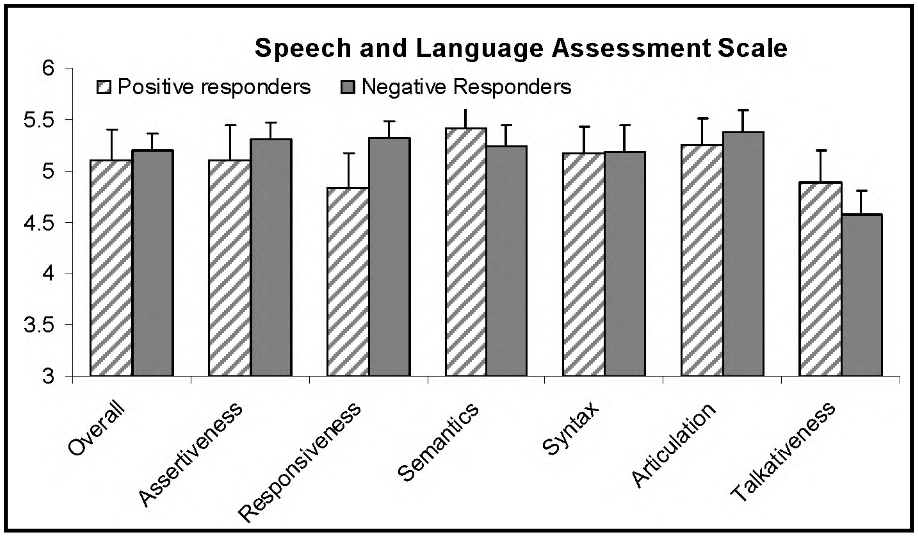

Figure 6.4: *Mean parental ratings (overall and per subscale) on the SLAS for the Positive and Negative Responders. A score of '4' corresponds to parents rating their child's language performance as equal to their child's peers; higher scores reflect better language ratings. Error bars are one standard error from the mean.*

Early correlates of speech segmentation viewed retrospectively

Figure 6.5 displays the grand average waveforms for 10-month-olds with lower and higher language quotients at five years, for familiarized and unfamiliar words presented in sentences. We first analyzed the 350-500 ms time window, where Kooijman et al. (2005) observed a significant ($p<.05$) WFE on left-hemisphere electrodes. With 23 subjects, again no main effect of Familiarity appears ($F_{1,21}$ =1.44, p =.24), and the original Familiarity by Hemisphere interaction is now insignificant ($F_{1,21}$=1.73, p =.20). The between-subjects factor Vocabulary Group does not interact with any within-subjects factor (p >.4). Furthermore, a separate analysis for the left hemisphere reveals that the once significant familiarity effect for 28 subjects is not significant for 23 subjects ($F_{1,21}$ =2.95, p=.10), which suggests a lack of power.

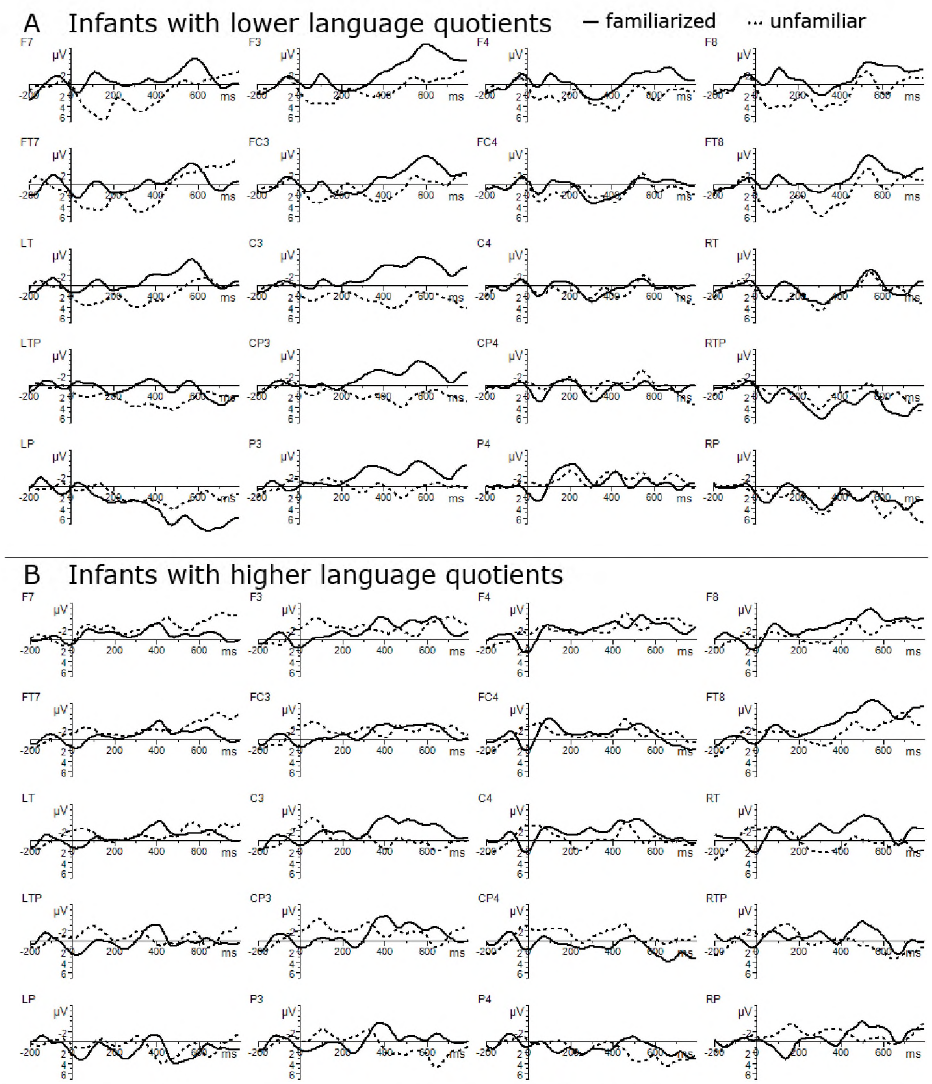

Figure 6.5: *Grand average waveforms for familiarized and unfamiliar words in continuous speech, for infants with lower (Figure 6.5A) and higher (Figure 6.5B) language quotients at five years. Electrodes are arrayed from most anterior (top) to most posterior (bottom), and from left to right as they were positioned on the scalp.*

Crucially, there is no interaction with Vocabulary Group ($F_{1,21}$ =0.31, p=.58): For neither group is the effect significant ($F_{1,10}$=2.79, p=.13; $F_{1,11}$<1, p=.44, for LLQ and HLQ, respectively). (See also Supporting Tables 3a-c, Appendix 3E,). Because Figure 6.5 shows that the WFE is almost absent for HLQ participants, yet widely distributed for LLQ participants, we conducted ANOVAs for 100 ms time windows (see Table 6.2). In no 100 ms time window was there a significant result for the WFE based on 20 lateral electrodes, for the interaction of WFE with Vocabulary Group, or for the WFE calculated separately for each group. When we focus only on left frontal electrodes, we observe for LLQ participants a marginal significant effect in the time windows 400–700 ms; however, there is no evidence that this effect differs significantly from the effect for HLQ participants (i.e. all interactions of Familiarity x Group p>.10). In sum, the analyses provide no support that language quotients at five years are retrospectively related to infants' WFE for words heard in continuous speech.

Table 6.2: *main effects of familiarity and interactions between Familiarity and Vocabulary Group for the Test phase, followed by main effects of Familiarity for each LQ-group, for 100 ms time windows (time-locked to the onset of critical words). The upper table reports these effects for all 20 lateral electrodes, and the lower table only for left frontal electrodes (* p<.10; **p<.05).*

Time (ms)	all electrodes 23 subjects ($F_{1,21}$) Familiarity	all electrodes 23 subjects ($F_{1,21}$) Familiarity*Group	all electrodes LLQ-group ($F_{1,10}$) Familiarity	all electrodes HLQ-group ($F_{1,11}$) Familiarity
0-100	< 1	3.44*	1.50	2.00
100-200	< 1	2.24	2.84	< 1
200-300	< 1	< 1	< 1	< 1
300-400	< 1	< 1	< 1	< 1
400-500	1.45	< 1	1.13	< 1
500-600	< 1	< 1	< 1	< 1
600-700	< 1	< 1	< 1	< 1
700-800	< 1	< 1	< 1	< 1

Time (ms)	left frontal elec. 23 subjects ($F_{1,21}$) Familiarity	left frontal elec. 23 subjects ($F_{1,21}$) Familiarity*Group	left frontal elec. LLQ-group ($F_{1,10}$) Familiarity	left frontal elec. HLQ-group ($F_{1,11}$) Familiarity
0-100	<1	5.34**	2.91	2.58
100-200	<1	1.97	2.90	<1
200-300	<1	<1	<1	<1
300-400	1.43	<1	1.60	<1
400-500	1.71	<1	3.64*	<1
500-600	1.37	<1	3.49*	<1
600-700	<1	<1	4.59*	<1
700-800	<1	<1	<1	<1

DISCUSSION

This study examined whether early speech segmentation ability, as indexed by a familiarity effect for words in continuous speech, continued to foreshadow language development to five years. We assessed this link in two ways: prospectively, by defining groups based on the polarity of the word familiarity effect at 10 months, and retrospectively, by creating groups based on average language quotients at five years. Neither type of analysis supported the existence of such a link. Together, the results suggest that early segmentation ability is not directly related to language profiles at five years.

However, it is clear that the presence of a WFE at 10 months is related to language profiles earlier than the age of five. In the present study, test phase WFE at 10 months was shown to correlate with the number of isolated word tokens infants needed to hear before a familiarization phase WFE appeared. Compared to the first two word tokens, infants with a negative WFE in the test phase showed a similar recognition effect by the third or fourth time a word was heard in familiarization. In contrast, infants with a positive-going effect in the test phase needed to hear these words nine to 10 times before showing recognition. Thus 10-month-olds with a clear WFE are at a head start compared to infants who do not show this effect. The difference between the children has gone, however, by the time they are five.

Note that Newman et al. (2006) indeed observed a relationship between infant segmentation ability and language performance up to five years. Recall, however, that Newman and colleagues analyzed groups at the extremes of vocabulary sizes at 24 months. Language performance varies along an extended continuum, and sampling extremes may magnify differences which are too small to be observed at an individual level (as in our analyses) or across a larger population (e.g., had Newman et al. included the remaining 70% of their earlier participants). Lack of variability in the standardized language tests used here is not likely to underlie the absence of a difference in our study, given that the children made errors, i.e., did not score at ceiling in these tasks (see Figure 6.3B). Moreover, we also observed no link between early word segmentation skill and later SLAS-scores. The results from the present study, then, suggest that speech segmentation skill in infancy does not predict language skill as far ahead as five years.

There are other factors that come into play by then, which could explain individual variation in language at five years, but are irrelevant for prelinguistic infants. First, going to (pre-)school has strongly impacts on children's development (e.g., Dickinson, 2001; Wasik & Bond, 2001). Second, general intelligence is a robust predictor of language outcomes (Bornstein et al., 2006). Third, specific linguistic abilities play a role, such as phonological awareness (e.g., Goswami, 2000), or speech decoding (e.g., Mody, Studdert-Kennedy & Brady, 1997; Marchman & Fernald, 2008). These factors, and potentially many others, combine to explain variation across children (and adults) in language performance. The infant WFE as an index of speech segmentation ability is indeed a crucial factor in the construction of an initial vocabulary; the studies reviewed in the introduction abundantly document this. At five years of age, however, its effects are no longer separately visible in children's language performance.

CHAPTER 6: EARLY SPEECH SEGMENTATION & LATER LANGUAGE

SUMMARY AND CONCLUSIONS

CHAPTER 7

ABSTRACT

This dissertation has investigated the neural markers of word recognition in infancy, and how these are related to vocabulary development. Section 1 of this concluding chapter first summarizes results from Chapter 2, which examined infant brain correlates of the three processes necessary for early word learning: visual categorization, word form recognition, and word-to-world-mapping. The word familiarity effect in Chapter 2, which was assessed by measuring nine-month-olds' brain potentials to single words presented in the context of pictures, will function as a steppingstone for summarizing the remainder of the chapters. Chapters 3-6 examined individual differences in recognizing word forms in more challenging conditions (i.e., which required infants to segment words from continuous speech). When 10-month-olds were tested on their ability to recognize word forms with different manipulations of the familiarization phase, we observed similar word form familiarity effects, with familiarized words eliciting a more negative ERP than unfamiliarized words did, but which differed slightly in latency and in distribution (Chapters 3 and 4). Since ERPs are crucially an on-line measure of word recognition, differences in latency (and in distribution) reflect difficulties in achieving word recognition. Therefore, Section 2 reviews the manifestations of the word familiarity effect observed in this dissertation, but also those observed in other infant studies assessing word recognition. Section 3 focuses on individual differences, and summarizes how infants' ability to recognize word forms in continuous speech is a crucial skill for later language development. Based on the research carried out in this dissertation, Section 4 presents some suggestions for future research. Finally, Section 5 ends with concluding remarks.

SUMMARY

Correlates of early word learning

Around their first birthday infants begin to talk, yet they comprehend words long before. Building a vocabulary not only requires infants to make a mapping between word and object, but crucially, also to identify both the object and word first. Neural markers of each of these processes were investigated in Chapter 2 by measuring ERP responses of nine-month-olds on basic level picture-word pairings. After a training phase of six picture-word pairings per semantic category, comprehension for novel exemplars was tested in a picture-word matching paradigm. ERP responses were measured at the onset of pictures in the training phase (visual categorization); at the onset of words in the training phase (word recognition); and at the onset of words in the test phase (word-to-world mappings).

ERPs time-locked to pictures in the training phase elicited a modulation of the Negative Central (Nc) component (Courchesne, Gaz & Norcia, 1981; Nelson, 1994; cf. de Haan, 2007). This Nc-component - a fronto-central negative wave peaking around 500 ms - is a typical infant ERP component associated with the processing of visual stimuli. Its amplitude is held to index attention or recognition memory. The Nc in Chapter 2 was attenuated both by category repetition (comparing the first three presentations versus the last three presentations of a semantic category) as well as by picture-type ratio (comparing multiple tokens versus constant tokens of a semantic category). Results from the former comparison suggest that infants were sensitive to the repetition of a semantic category, regardless of the picture-type ratio, which implies that within six presentations infants can build a memory trace of a semantic category and recognize it subsequently. The timing of the Nc further suggests that infants have identified the visual token within 500 ms after its onset. The same infants were also sensitive to the picture-type ratio (regardless of any repetition effects): the Nc was larger when the pictures were varied than when they remained constant. This implies that infants allocated more resources (i.e. more attention) to identify different tokens of the same semantic category than when the token remained constant.

ERPs time-locked to words in the training phase, on the other hand, elicited a large positive wave, which became more negative with repetition. This effect is the word familiarity effect, which appears around 400 ms after the word is presented on frontal electrodes. Each word was presented a second after the onset of a picture, while the picture remained on the screen. However, in contrast to the results from the ERPs corresponding to visual categorization, there was no influence of picture type-token ratio on the ERPs time-locked to the words; consequently, these results again imply that infants have identified the concept of each picture before a word was presented.

Results from the test phase provided clear support for the conclusion that infants integrated word meanings with (novel) picture context. Here, infants showed different ERP responses for words that did or did not align with the picture context: a phonological mismatch (N200) and a semantic mismatch (N400). The phonological mismatch suggests that infants were expecting a different word form than the one they actually heard. This implies that nine-month-old can build expectations of a phonological word form corresponding to novel tokens of a semantic category; in other words, after a short training session of six picture-word pairs per semantic category, infants are able to internally generate a label for a token they had not seen before, but that belongs to a category they have some experience with. The subsequent semantic mismatch reflects the additional difficulty that infants then have to integrate the meaning of the word they hear with the picture they see.

Together, results from Chapter 2 were informative of visual categorization, word recognition and word-to-world-mappings, all three crucial processes for vocabulary construction. The word familiarity effect in Chapter 2 was observed when the nine-month-olds listened to single tokens of words (in the context of pictures), whereas infants generally encounter words presented within continuous speech. In Chapters 3 and 4 the word familiarity effect was also present when we then focused on 10-month-olds' ability to recognize word forms presented first in various amounts of continuous speech. The following section reviews the word familiarity effect.

The word familiarity effect

The word familiarity effect is an infant ERP effect associated with auditory processing of words: ERPs corresponding to familiar(-ized) words are more negative in voltage around 400 ms than ERPs corresponding to unfamiliar(-ized) words. This effect is most pronounced on (left-) frontal electrodes. The use of ERPs as an on-line measure of word recognition inspired us in Chapters 3 and 4 to further examine the amount and type of familiarization needed for infants to recognize the familiarized word forms: Chapter 3 examined whether 10-month-olds were able to recognize a word that was presented previously once either within an utterance or in isolation. In Chapter 4 we assessed whether 10-month-olds were able to recognize words when both the familiarization and test phases consisted of continuous speech. Table 7.1 gives an overview of the manifestations of the word familiarity effect, not only in this dissertation, but also in other infant studies.

The comparison of the word familiarity effect across studies shows that this effect is present when it assesses familiarity of word meaning, as well as familiarity of word form (i.e. before infants know the meaning of the words).

Learning the meaning of words presupposes infants' learning of the word forms. For both types of familiarity, the effect is most often present on left-frontal electrodes, around 400 ms after the onset of critical words. Nevertheless, there are some differences in how this effect is manifested each time. First, it appears that the word familiarity effect has a positive instead of a negative polarity when word segmentation ability is tested in the youngest age range (six-month-olds: Männel & Friederici, 2010; seven-month-olds: Kooijman, 2007).

Table 7.1: Manifestations of the word familiarity effect. First the word familiarity effects in this thesis are given, then word familiarity effects reported by other researchers, in alphabetical order (Note FP = Familiarization phase; TP = Test phase)

Authors	**Familiarity Tested**	**Age** (months)	**Experimental manipulation**	**Time window**	**Polarity** (relative to unfamiliar)	**Distribution**
Chapter 2	word meaning	9	6 single tokens, with picture context	300-600	Negative	frontal
Chapter 3	word form	10	*FP*: 1 token (within or without continuous speech) *TP*: 1 single token (familiarized or unfamiliar)	200-650	Negative	broad or left-frontal, depending on vocabulary size
Chapter 4	word form	10	*FP*: 8 tokens within utterances *TP*: utterances: 2 with familiar and 2 with unfamiliar words	*FP*: 350-500 *TP*: 220-500	Negative	*FP*: broad *TP*: frontal
Addy & Mills (2005; as reported in Sheehan & Mills, 2008)	word form/ meaning	3-4; 6-8; 10-11	single words (familiar, unfamiliar, backwards)	3-4: 175-550 6-8: 200-500 10-11: 200-500	3-4: Positive 6-8: Negative 10-11 Negative	not reported
Conboy & Mills (2006)	word meaning (bilinguals)	20	known versus unknown words, in dominant and non-dominant language	200-400	Negative	dominant language: frontal; non-dominant: broad
Friedrich & Friederici (2008)	word meaning	14	8 novel tokens either constantly or randomly paired with novel pictures.	200-500	Negative	fronto-lateral
Friedrich & Friederici (2011)	word meaning or word form	6	As in Friedrich & Friederici (2008)	200-800 (both for constant and rotated pairings)	Negative	frontal
Goyet et al. (2010)	word form	12	*FP*: 10 single tokens of bisyllabic words *TP*: utterances: 6 with familiar and 6 with unfamiliar words	*FP*: 300 -450 *TP*: 350-500	Negative	*FP*: right-frontal *TP*: broad

Authors	**Familiarity Tested**	**Age** (months)	**Experimental manipulation**	**Time window**	**Polarity** (relative to unfamiliar)	**Distribution**
Kooijman et al. (2005)	word form	10	*FP*: 10 single tokens of trochaic words. *TP*: utterances: 4 with familiar and 4 with unfamiliar words	*FP*: 200-500 *TP*: 350-500	Negative	*FP*: broad *TP*: left
Kooijman et al. (2009)	word form	10	*FP*: 8 single tokens of iambic words. *TP*: utterances: 2 with familiar and 2 with unfamiliar words	*FP*: 200-500 *TP*: 370-500 (from strong syllable)	Negative	*FP*: broad *TP*: broad
Kooijman (2007)	word form	7	As in Kooijman et al. (2005)	*FP*: 200-500 *TP*: 350-450	*FP*: Negative *TP*: Positive	*FP*: left-frontal *TP*: right-frontal
Männel & Friederici (2010)	word form	6 & 12	*FP*: 8 tokens within utterances, either with or without pitch accent *TP*: single words: 4 familiar, 4 unfamiliar	6-m-olds: 500-800 (only with pitch) 12-m-olds: 400-700 (both with or without pitch)	6-m-olds: positive 12-m-olds: negative	6-m-olds: (right-)frontal 12-m-olds: frontal
Mills et al. (1993)	word meaning	20	known versus unknown single words	125-250; 275-450	Negative	left-temporal
Mills et al .(1997)	word meaning	13-17	As in Mills et al. (1993)	125-250; 275-450	Negative	broad
Mills et al. (2004)	word meaning	14 & 20	known vs. mispronunciations or nonsense words	14-m-olds: 200-400 (known vs. nonsense) 20-m-olds: 200-400 (known vs. mispr./ nonsense)	Negative	14-m-olds: broad; 20-m-olds left-temporal
Mills et al. (2005)	word meaning	20	auditory single novel words; half of them matched to novel objects before	200-500	Negative	broad (larger to the left for infants with larger vocabularies)
Parise et al. (2010)	word form/meaning	5	own versus stranger's name	100-380	Positive	fronto-central
Thierry et al. (2003)	word meaning	11	familiar versus unfamiliar words	200-350	Negative	broad

Authors	Familiarity Tested	Age (months)	Experimental manipulation	Time window	Polarity (relative to unfamiliar)	Distribution
Thierry et al. (2007)	word meaning	9 -12	see Thierry et al. (2003)	200- 400 (but not present for 12-m-olds)	Negative	9-m-olds: anterior 10- &11-m-olds: broad
Thorkildsen et al. (2009)	word meaning	20	5 single tokens (for both novel and known words) in context of pictures	200-800 ms	Negative	(left-) frontal
Toneinen et al. (2009)	word familiarity	neonates	artificial speech (3-syllabic-words), first versus second or third syllable (S)	260-440	Negative for S1>S2 or S3	broad
Zangl & Mills (2007)	word meaning	6 & 13	known versus unknown words, presented in infant or in child directed speech	200-400 (only for 13-month-olds)	Negative	broad

There are several reasons why these polarity differences are observed: these could be the result of the many changes in brain maturation that take place between seven and ten months, such as the slow closing of the fontanels and increased dendritic growth and pruning. It could also reflect differences in how the underlying brain mechanisms are involved. However, recent findings suggest that it is not likely that changes in brain maturation underlie these changes in polarity. For instance, in Chapter 5 we compared infants at seven months who showed either a positive or negative familiarity effect in the test phase (words within continuous speech), on their later language development. Although these two groups of infants were virtually of the same age, and presumably with same states of brain maturation, those infants who initiated a recognition response similar to their peers at 10 months excelled in their language development at three years. Moreover, regardless of the polarity of the familiarity effect in the test phase, the majority of the same seven-month-olds displayed a negative familiarity effect when word recognition was measured in an easier situation (i.e., in the familiarization phase, which comprised 10 tokens of the same word in isolation). A word familiarity effect with negative familiarity was also recently observed for six-month-olds who were familiarized with eight tokens of a novel word in the context of a picture (Friedrich & Friederici, 2011). Hence, it seems that the polarity difference does not reflect changes in brain maturation between infants younger and older than 10 months, but rather differences in how the underlying brain mechanisms are involved in word recognition. The situation of continuous speech in which very young infants need to achieve word recognition could be so challenging that they might have less stable representations of these word forms than when the situation consists of single words, which could in turn influence their ease of access and retrieval of words.

The word familiarity effect is also known as the N200-400/500 (Mills et al., 2005); however, its latency can differ depending on the situation in which it is tested, as Table 7.1 further shows. Although the word familiarity effect generally peaks around 400 ms, its onset can vary; for instance, Chapter 4 shows that infants initiated a recognition response in the familiarization phase that was 130 ms later than the recognition response in the test phase. As was discussed then, differences in latencies are associated with difficulties of the situation in which infants need to achieve word recognition. If word recognition is relatively easy, infants can initiate a recognition response around 200 ms; if it is more difficult, the response is delayed.

Besides differences in polarity or in latency, manifestations of the word familiarity effect can also differ in distribution. Such differences have also been linked to the difficulty of the situation in which infants' ability to recognize words is tested. Smaller distributions of the familiarity effect reflect that infants require fewer resources to recognize words, suggesting an easier situation to accomplish this. We have seen this for instance in Chapter 3 and 4. In Chapter 3, infants with larger vocabularies had more local familiarity effects for the situation in which they need to recognize a word presented before in isolation, but broader familiarity effects when the same word was first presented within an utterance. Similarly, in Chapter 4, infants needed more resources to build up a memory token for words repeatedly presented in continuous speech than to recognize these words subsequently again in continuous speech. Again, the former situation is in all probability more difficult than the latter, requiring infants to use more resources. Although differences in distribution generally imply a comparison between a broad versus a focal distribution, the word familiarity effect is in almost all cases present on left-frontal electrodes. This suggests that the same underlying brain mechanisms are again and again involved in recognizing words across studies.

The word familiarity effect either involves some sort of word form repetition, or distinguishes between words with and without meaning to the infants. For infants, it takes the form of an increased frontal negativity for familiarized words. When adults, on the other hand, listen to word (form) repetitions, a different ERP pattern is observed: compared to the ERP for unfamiliarized words, the ERP for familiarized words are more positive on centro-parietal electrodes (i.e., becomes less negative by repetition; Rugg, 1985). This is the case both when adults are native listeners, with words carrying meaning, as when adults are foreign listeners, with words carrying no meaning (Snijders, Kooijman, Hagoort & Cutler, 2007). Hence, compared to the infant word familiarity effect, the adult ERP effect differs substantially in distribution and in polarity. However, there are some studies on artificial language processing that observed a similar effect in adults as the infant word familiarity effect. They linked a fronto-central increase in negativity around 400 ms for word repetitions with novel word learning from continuous speech (Abla, Katahira & Okanoya, 2008, Cunillera, Toro, Sebastián-Gallés & Rodríguez-Fornells, 2006; Sanders, Newport & Neville, 2002). Hence, it could be that ERPs corresponding to the initial learning of word forms in infancy reflect involvement of the same mechanisms as ERPs corresponding to the learning of nonsense forms by adults. Nevertheless, if this increased negativity indeed reflects the on-line creation of word-like representations in adults, as was suggested (Abla et al., 2008; Cunillera et al., 2006), it is unclear why the same pattern is then not observed when adults listen to repetition of single pseudo-words (e.g. Rugg, Doyle & Wells, 1995). In short, it is uncertain as yet how the infant word familiarity effect relates to adult counterparts.

To summarize, the word familiarity effect takes the form of an increased negativity around 400 ms that is predominantly present on left-frontal electrodes, for familiar words relative to unfamiliar words. Like the Nc, it is a typical infant ERP effect, because it has no clear counterpart in adults tested in the same situations. Similarities in the manifestations for either word form or word meaning recognition suggest that infants use the same brain mechanisms to detect either form of word recognition. Subtle differences in the manifestation of the word familiarity effect, on the other hand, can reflect difficulty of the situation in which infants accomplish word recognition. Indeed, a difference in latency increases the worth of ERPs as an on-line measure of word recognition. This measure allows us to see *when* infants accomplish word recognition in various situations, and allows for a comparison of how difficult each of these situations is.

In this dissertation the word familiarity effect has been observed for words presented in isolation (Chapters 2 and 3) as well as for words presented within utterances (Chapters 3 and 4). In the latter situations infants were required to extract the words from speech. It is their ability to find word boundaries, i.e. word segmentation, that has been demonstrated in this dissertation over and again to be related to infants' later language development up to three years. The following section discusses the relevance of speech segmentation ability in more detail.

Speech segmentation ability as a pointer for language development

Infants' ability to extract words from continuous speech is vital for building a vocabulary. As Newman and colleagues (Newman, Bernstein Ratner, Jusczyk, Jusczyk & Dow, 2006) have shown, a behavioral measure of speech segmentation is related to later language development. This dissertation uses the ERP word familiarity effect for words presented (first) in continuous speech as an index of infants' speech segmentation ability. It reports four studies relating this ERP segmentation measure to later language development. In all these studies target words in the speech segmentation task followed the typical Dutch pattern of strong-weak bisyllabic words. Hence, the importance of speech segmentation ability in this thesis actually reflects infants' ability to recognize language-specific prosodic patterns and use these as a cue to detect word boundaries. As is shown in these four studies, this is an important ability. First, Chapter 3 shows that 10-month-olds who recognized words previously presented once, within an utterance, later had larger vocabularies at 12 and 24 months than those 10-month-olds who could not perform this task. Language development was here measured by asking their parents to tick those words that their child would probably understand from a long list of words.

Second, in Chapter 4, 10-month-olds who initiated a larger recognition response for words occurring again in continuous speech excelled in an eye-tracking task measuring their ability to recognize known words at 16 months: The larger the size of the word familiarity effect at 10 months, the longer infants fixated an object after hearing the spoken object name.

Chapter 5 further illustrated the link between early segmentation ability and later language development: Those seven-month-olds with a word familiarity effect similar to the 10-month-old norm displayed significantly higher language scores at three years of age than those seven-month-olds with a positive word familiarity effect. Language development was assessed here (and in Chapter 6) by standardized language tests measuring children's receptive and expressive language skills. Hence, Chapters 3, 4, and 5 together demonstrate that with a variety of follow-up measures for language development, the ERP index of speech segmentation ability serves as a robust predictor of the degree of later language development up to three years.

Finally, Chapter 6 shows that the relationship between the word familiarity effect at 10 months and language scores at five years was no longer present: The advantage of better segmentation ability wears off when infants have reached the age of five years and started going to school.

This dissertation has demonstrated that individual differences in infants' speech segmentation skill are linked to their later language development up to three years. Clearly, the ability to find words in continuous speech has implications for infants' language development: Infants who already show a word familiarity effect with negative polarity continue to outperform their peers who do not show such an effect.

In Chapters 3, 4, and 5, there were clear correlations between the word familiarity effect shown by infants and subsequent language scores when these infants became toddlers: The relationship was repeatedly visible at the individual level. Newman et al. (2006), who were the first to demonstrate the relevance of speech segmentation skill, report a relationship that is visible at the group level, using a behavioral marker of speech segmentation ability. They could observe this significance of speech segmentation skill for later language development when they collapsed infants' performance over several of their studies. Note that 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. Also, due to the post hoc nature of their study, only the infants at the extreme boundaries of two-year-olds' vocabulary sizes were compared: only those children were followed whose vocabularies at 24 months were at the top and bottom 15% of a larger cohort of infants. Assessing the predictive relationship for infants' language skills covering the full range of vocabulary outcomes, as was possible in this dissertation, further strengthens the hypothesis that speech segmentation ability continues to give infants a head start for language development. This suggests that an electrophysiological marker of speech segmentation ability is a particularly sensitive measure: results showed that ERPs are a very valuable tool to study how word segmentation in the first year of life is related to future development.

This dissertation presents clear evidence that speech segmentation skill is an important precursor to later language development, but it does not reveal why it is that some infants have better speech segmentation skill than others. All participants were healthy monolingual infants recruited from the same small area (Nijmegen). The subject groups showed little variation with respect to socio-economic or parental factors. Yet there are numerous factors that could possibly explain the variation in infant's ability to find words in continuous speech, including auditory ability and genetic endowment, which could influence the course of each individual aspect of language development. Clearly more research is needed to reveal the origins of early speech segmentation ability.

To summarize, the skill of recognizing words within continuous speech is vital for building a vocabulary and hence unquestionably related to later language development. Infants mainly hear continuous speech in the first year of life; it is their only resource for initial word form learning. The building of a vocabulary will be hindered if infants cannot find the word boundaries in speech. This dissertation provides robust evidence of the relevance of speech segmentation ability to their vocabulary development.

SUGGESTIONS FOR FUTURE RESEARCH

This dissertation investigated the neural markers of word recognition in infancy, and how these were related to vocabulary development. Both for word form and word meaning familiarity, we observed a frontal negativity around 400 ms for familiarized words relative to unfamiliar words. This effect is the word familiarity effect. However, although this effect is manifested in many infant studies assessing word recognition, it is unclear how this effect relates to adult ERP effects. Word recognition in adults is characterized by a modulation of the N400: Although it has a similar latency, the adult familiarity effect typically shows a decrease in negativity for familiarized words, which is predominantly present on centro-parietal electrodes. Therefore, more research is needed to achieve a full understanding of the developmental pattern of the word familiarity effect from infancy to adulthood, by assessing word (form) recognition at various ages between infancy and adulthood.

A major finding of this dissertation is that speech segmentation ability, as indexed by the word familiarity effect, is related to later language development up to three years. This result gives rise to at least two new directions of research. First, why is it that some infants display better segmentation ability than others? There are several possible reasons that could explain the ontogeny of this ability, ranging from genetic factors, to differences in the mother's pronunciation, or it could be bootstrapped from a more advanced mechanism of speech processing.

There are several studies that linked infants' later language development with their performance in early infancy on linguistic tasks other than measuring speech segmentation ability. It would therefore be interesting to examine whether speech segmentation skill is also retrospectively related to a measurable language skill that has been linked with future language development. For instance, Kuhl and colleagues (Kuhl, Conboy, Padden, Nelson & Pruitt, 2005; Rivera-Gaxiola, Klarman, Garcia-Sierra & Kuhl, 2005) demonstrated that the ability to distinguish between native or between non-native sounds was related to vocabulary development up to 30 months: Infants with better native phonetic perception acquired their first language faster, whereas infants with better non-native phonetic perception, indicative of less native-language specialization, are more delayed. The "native language magnet theory-expanded" model of Kuhl et al. (2008) suggested that infants between six and 12 months develop neural networks specifically dedicated to native language processing, which narrows infants' initial universal ability to discriminate between all possible speech sounds to the ability to discriminate only speech contrasts relevant to their language. The infants tested originally were then between six and 12 months, which is about the same age as at which word segmentation skill can be assessed. If the same infants who demonstrate better native phonetic perception also excel in a task measuring their speech segmentation ability, this would then imply that both abilities originate from the same advanced mechanism of native speech processing.

Nevertheless, regardless of the origins of speech segmentation ability, this dissertation has shown that there is a robust link between early word recognition and later language development up to three years. However, speech segmentation ability was only assessed in typically developing children, who represent a sample of the normal population. As a third suggestion for future research, it would be interesting to see whether infants at risk of severe language impairments or at risk of dyslexia show deviant ERP word familiarity effects compared to infants not at risk. If infants at risk show such deviant ERP responses, this would not only further stress the relevance of speech segmentation ability for language development, but it might also provide clinical research with a handle to detect language impairments even at an age before infants start to speak words. The sooner speech impairments are detected, the earlier intervention might start. Moreover, together with this dissertation's finding that speech segmentation ability in the normal population partly explains variation in language development, if new research shows that infants at risk indeed fail in detecting words in continuous speech, this could then stimulate clinical research to develop intervention strategies that aim to improve infants' speech segmentation ability. After all, it is the ability to detect possible word-like units in continuous speech that clearly forms an important foundation for vocabulary initiation.

CONCLUSIONS

This dissertation examined the electrophysiological correlates of word (form) learning in the infant brain. It has provided new and useful insights in how infants acquire their first language in a period of their life in which it is hard to register the development of their receptive language skills. All experimental chapters used ERPs as a non-invasive yet on-line reflection of how infants process auditory words in the second half of their' first year of life.

One major finding of this dissertation is that infants initiated a word recognition response that was remarkably similar when it concerned word meaning (Chapter 2) as when it concerned word forms (Chapters 3, 4; Kooijman, 2007)). In both cases infants showed a negative ERP effect on left-frontal electrodes around 400 ms for familiarized relative to unfamiliarized words, termed here the word familiarity effect.

This thesis further assessed how many times and in which circumstances a word needs to be presented before a word familiarity effect was elicited for 10-month-olds in general: Infants needed to hear a word seven to eight times in continuous speech, or just once when it was presented in isolation. Hearing a word once within an utterance only sufficed for those infants with higher vocabularies at 12 and 24 months.

A final finding of the research carried out in this dissertation is that the word familiarity effect for words presented in continuous speech can be taken as a sensitive measure for subsequent language development. Crucially, infants had to find the boundaries in the spoken language (i.e. segment the speech signal into its component words) to start recognizing these words as familiar. We repeatedly observed a clear relationship between the presence of this word familiarity effect and future language profiles. On varying behavioral 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) this dissertation has shown that this ERP segmentation effect served as a robust predictor of the degree of later language development. Around five years, however, this initial advantage of early speech segmentation ability was no longer noticeable.

Hence, 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 further demonstrated the merit of ERPs as an on-line measure for speech segmentation: this measure allows us to see not only whether but also when it is that infants initiated a word recognition response. 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 till at least the age of three year.

CHAPTER 7: SUMMARY & CONCLUSIONS

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APPENDICES

APPENDIX 1: STIMULUS MATERIALS

APPENDIX 2: ERP FIGURES

APPENDIX 3: SUPPORTING TABLES

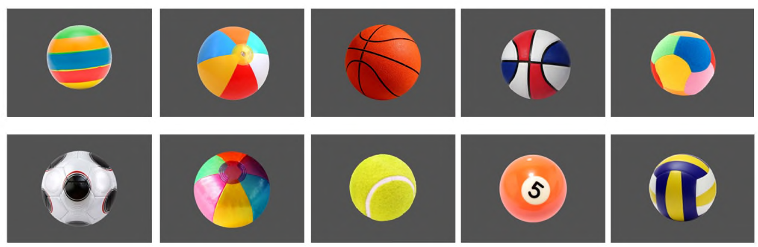
APPENDIX 1: STIMULI

APPENDIX 1: STIMULUS MATERIALS

APPENDIX 1A: VISUAL STIMULI OF CHAPTER 2

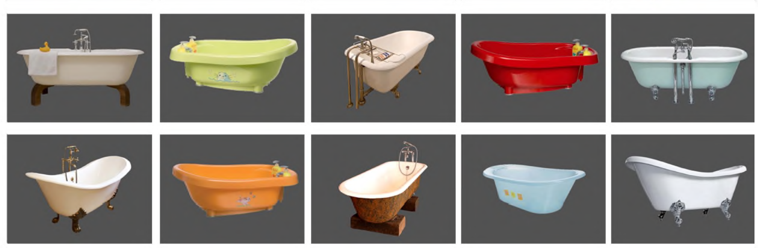
1 Babies

2 Balls

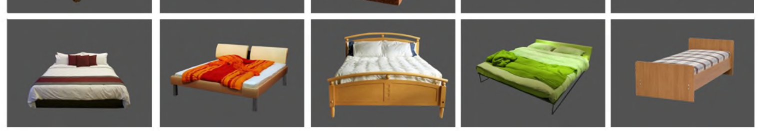


3 Bananas

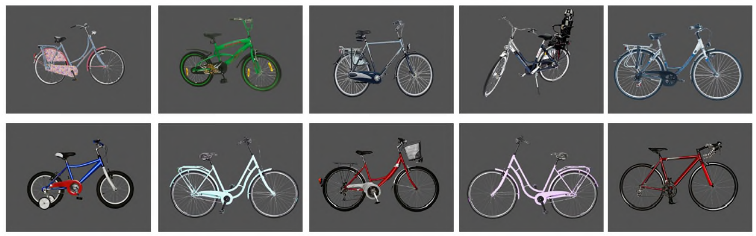
4 Baths



5 Beds



6 Bicycles

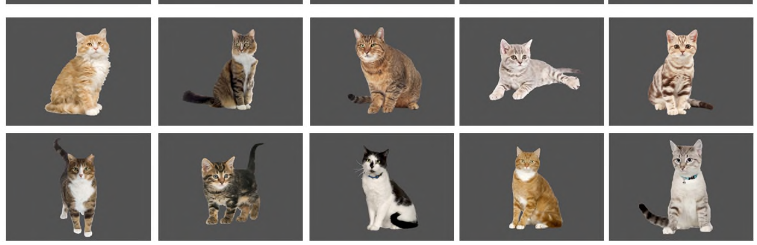


7 Books

8 Bottles

9 Cars

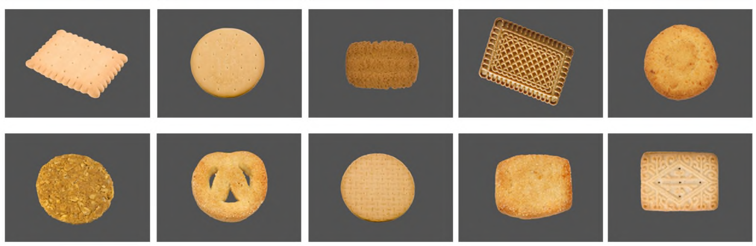
10 Cats



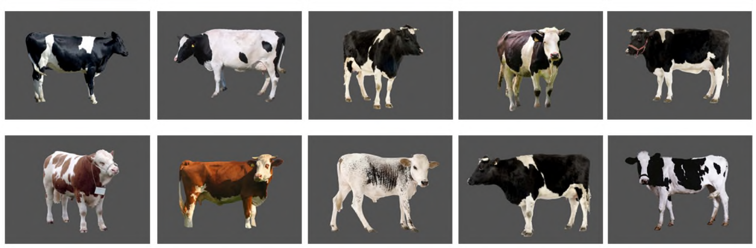
11 Chairs

12 Coats

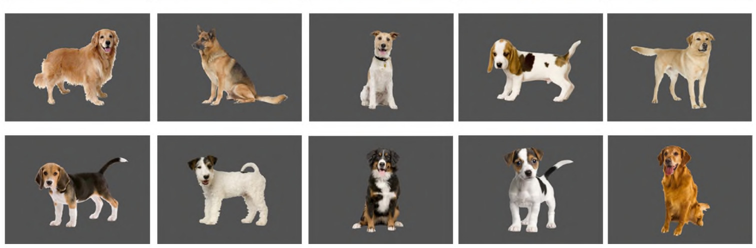
13 Cookies



14 Cows



15 Dogs

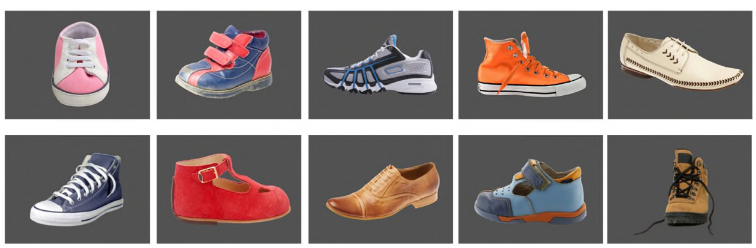


16 Feet

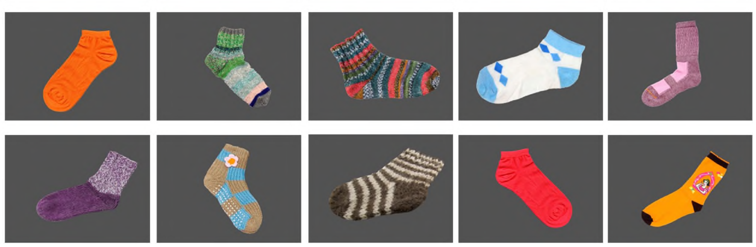
17 Hands

18 Mouths

19 Shoes



20 Socks



APPENDIX 1B: STIMULUS MATERIALS FROM CHAPTER 3

Target words are in bold; *pseudowords* are italicized as well.

nr.	word pairs	Familiarization sentences List A	Familiarization sentences List B
1	**beller-karig**	Die **beller** rijdt verkeerd	Ze zijn **karig** met woorden
		De woeste **beller** spreekt luid	Ook daarom geven we **karig** geld uit
2	**broedsel-leisel**	Het **broedsel** vliegt weg	Het oude groene **leisel** werkt niet
		Het jonge **broedsel** komt uit	Het slappe **leisel** bood houvast
3	**daalder-ruimte**	De nogal antieke **daalder** is kwijt	Veel **ruimte** is er niet.
		Die losse **daalder** vond ik thuis	Zijn buro neemt **ruimte** in beslag
4	**danser-schutter**	Weer is de mooie **danser** te laat	Aan een **schutter** gaf hij melk
		De **danser** doet zijn best	Hij is een goed **schutter** geworden
5	**emoe-orka**	Dat is een **emoe** van de boerderij	De **orka** kan heel goed kunstjes leren
		De **emoe** komt vooral voor in Australië	Ik zag een **orka** op de televisie
6	**gieter-*dantel***	De zware **gieter** staat buiten	Dat lijkt een erg ***dantel*** beest
		De **gieter** ligt binnen	Zo **dantel** is ze nooit
7	**hinde-drummer**	De **hinde** sprong net op tijd weg	De **drummer** speelt soms in de stad
		Daar eet een **hinde** het verse gras	Er is een **drummer** in het café
8	**kajak-logo**	Zo'n **kajak** is alleen voor wedstrijden	Zo'n **logo** heb ik eerder gezien
		Hij bouwt een echte **kajak** van dat hout	Ze schilderen het echte **logo** op het raam
9	**kiwi-sheriff**	Die grote **kiwi** heeft een grote snavel	Een grote **sheriff** ziet er indrukwekkend uit
		Natuurlijk is een **kiwi** ook een vrucht	De **sheriff** is erg belangrijk voor het dorp
10	**knolzwam-sitar**	Toch is ook de **knolzwam** al vrij zeldzaam	Een **sitar** is een bijzonder maar simpel ding
		Een **knolzwam** zie je soms in het bos	Tegenwoordig zie je de **sitar** niet zo vaak
11	**lastig-korter**	Die klus wordt **lastig** voor haar	Een **korter** stuk wordt geplaatst
		Het is weer een keer **lastig** werk	Met zo'n **korter** touw kun je ook
12	**leidster-kruidig**	De erg strenge **leidster** geeft op	Dat was een erg **kruidig** drankje

		De nare **leidster** gaat weg	Vader lust graag **kruidig** eten
13	**lener-*narrig***	Die jonge nieuwe **lener** ziet het	Een **narrig** gevoel slaat toe
		De oude **lener** betaald zijn schuld	Dat is een vrij **narrig** bericht
14	**loper-woedend**	Ze ziet de grillige **loper** liggen	Zij doet **woedend** haar beklag
		Hij doet snel met zijn **loper** open	Heel **woedend** holt hij naar huis
15	**malen-serre**	Het grof **malen** is nodig	Ze tekent een glazen **serre** erbij
		Het moet heel lang **malen** daarna	Hij heeft een **serre** gemaakt
16	**mammoet-hommel**	Er is een oude **mammoet** in het museum	Het is een oude **hommel** met gele strepen
		Die kleine **mammoet** zwemt in de rivier	Een kleine **hommel** zit op het gordijn
17	**medley-tuba**	De **medley** hoorde ik op de radio	De **tuba** is een erg groot instrument
		Een hele mooie **medley** hoor je slechts zelden	Met een mooie **tuba** maak je veel indruk
18	**metro-sandwich**	Met de **metro** ben je sneller thuis	Op de **sandwich** zit kaas en ham
		In een grote **metro** kunnen veel mensen	Na zo’n grote **sandwich** zit je vol
19	**mosterd-pelgrim**	Die oude **mosterd** smaakt echt niet meer goed	De oude **pelgrim** maakt een lange reis naar Lourdes
		De **mosterd** wordt verkocht bij elke slager	De **pelgrim** is blij met de openbaring
20	***nantig-freinsel***	Zo’n ***nantig*** kado doet me goed	Dat is een aardig **freinsel** geworden
		Ze zoekt een zeer ***nantig*** feest	Jan gooit dat **freinsel** weg
21	**otter-gondel**	Die **otter** is dol op spelletjes doen	Die **gondel** wordt elk jaar weer gebruikt
		Piet zag een **otter** uit een ander land	Dat is een **gondel** van de stevige slager
22	**parka-maestro**	Ik draag een dikke **parka** van wol	Het is de dikke **maestro** uit Italië
		Die andere **parka** kan ik nog wel aan	De andere **maestro** is een nogal druk mannetje
23	**poema-fakir**	Daar loopt een moedige **poema** uit het circus	Er is een moedige **fakir** op de kermis
		De **poema** kijkt nieuwsgierig naar de tijger	De **fakir** loopt zomaar over de kolen

24	**python-hofnar**	De **python** ziet er nogal gevaarlijk uit	De **hofnar** maakt weer eens rare grappen
		Daar zie ik een boze **python** liggen	De koning hoort de boze **hofnar** vallen
25	**raadsel-nieter**	Met een groot **raadsel** zitten	Een **nieter** wordt gebruikt
		Het **raadsel** is opgelost	Ze is die grijze **nieter** kwijt
26	**raster-galig**	Daar is een mooi **raster** geplaatst	De huid is **galig** geworden
		Het **raster** ligt thuis	Het lijkt **galig** weefsel te zijn
27	**rechter-*loenend***	Het stoepje is **rechter** gelegd	En haar ***loenend*** kalf is lief
		Het was **rechter** dan eerst	Dan kijkt hij ***loenend*** weg
28	**ronde-gulden**	De zeer lange **ronde** was moeilijk	Het mes heeft zo'n **gulden** gloed
		De klassieke **ronde** is populair	Zo'n zwaar **gulden** zwaard roest
29	**sauna-pudding**	In een warme **sauna** kun je goed ontspannen	Na een warme **pudding** drink ik graag koffie
		De **sauna** is behoorlijk ver weg	De **pudding** is niet goed gelukt
30	**serre-krekel**	Hier in de groene **serre** kan je zitten	Ik zag een groene **krekel** in het gras
		Die **serre** bij het restaurant is mooi	Die **krekel** kan aardig wat lawaai maken
31	**slede-krokus**	Een **slede** heb je in sommige landen echt nodig	Een **krokus** is ook heel leuk om kado te geven
		Die roze **slede** is erg opvallend	De roze **krokus** zie je vaak
32	**sultan-monnik**	De **sultan** bestuurt het kleine landje	De **monnik** wiedt zijn tuintje dagelijks
		De strenge **sultan** regeert met straffe hand	De strenge **monnik** draagt een zware habbijt
33	**tabberd-ketjap**	De **tabberd** hangt nu aan de kapstok	De **ketjap** staat in dat blauwe kastje
		Dat is de nieuwe **tabbard** uit Spanje	Geef mij die nieuwe **ketjap** eens aan
34	**tijger-geler**	De wilde **tijger** springt	Het is **geler** dan voorheen
		Het lijkt een vrij rustige **tijger** te zijn	Ze ziet wat **geler** dan anders
35	**toffee-klamboe**	Er ligt nog een oude **toffee** daar	Daar kun je een oude **klamboe** kopen
		Die **toffee** smaakt heerlijk bij de thee	Die **klamboe** van mijn ouders is kapot
36	**trekker-gaatje**	De kleine **trekker** doet het	Ze ziet dat **gaatje** in de muur
		Op de kleine rode **trekker** zit iemand	Het **gaatje** is weer gedicht
37	***vanter*-ringen**	Ze hoort een rijk ***vanter*** zuchten	Die kleine roze **ringen** glanzen
		Geen ***vanter*** gaat op zoek	Hij heeft die gewone **ringen** gekocht

38	**viking-zwaluw**	Die kleine **viking** is niet sterk maar slim	De kleine **zwaluw** kan heel goed vliegjes vangen
		Dat is die andere **viking** met veel vijanden	Ik zie een andere **zwaluw** in de wei
39	**vuren-goedig**	Het snelle **vuren** was over	Het is echt geen **goedig** mens
		Bij het rappe **vuren** ging het mis	Hij stelt zich **goedig** voor
40	**zelfde-kuren**	Ik denk dat **zelfde** vaak	Ze deed **kuren** bij haar
		Volgens de **zelfde** regels leven	Die **kuren** zijn echt heel gezond

APPENDIX 1C: STIMULUS MATERIALS FROM EXPERIMENT 4.1

nr.	word	Familiarization sentences	Test sentences
1	**bellers**	Het gesprek van **bellers** loopt uit	Alle **bellers** stappen laat uit
		In de trein zijn **bellers** niet gewenst	Deze **bellers** hebben geen haast
		Die woeste **bellers** spraken luid	Spaanse **bellers** hoor je goed
		Dan gaan de **bellers** praten	Vaak gaan **bellers** op reis
		Achterin zitten ook **bellers**	
		Er was geen ruimte voor **bellers**	
		Die keuze maken **bellers** snel	
		Voor het gemak gaan **bellers** kletsen	
2	**drummer**	Hij was **drummer** van een band.	Meteen sloeg de **drummer** zijn slag
		Voor je **drummer** stond alles klaar	Op slag was haar **drummer** verliefd
		De grote trom was van één **drummer**	De stier ging zijn **drummer** volgen
		Veel fans waren gek op de **drummer**	De mus heeft een **drummer** gehoord
		Elke band heeft een **drummer** nodig	
		De populaire **drummer** zong graag	
		De leuke **drummer** hield van slagroom	
		Een goede **drummer** heeft werk	
3	**fakirs**	Dove **fakirs** zie je niet vaak.	De kleine **fakirs** zijn gegroeid
		Oude **fakirs** hebben een baard	Een leeuw maakt **fakirs** bang
		Dit bed is voor de **fakirs**	Die enge **fakirs** zijn magisch
		De messen zijn voor **fakirs**	Er waren **fakirs** verdwenen
		In het circus traden **fakirs** op	
		Later willen de broers **fakirs** zijn	
		Alleen echte **fakirs** snappen pijn	
		Vrijwel alle **fakirs** zijn mager	
4	**gieters**	De boer heeft **gieters** nodig	Op de weg staan **gieters** nooit
		Zij vult de **gieters** met sop	De merrie heeft **gieters** in huis
		Een tuin kan niet zonder **gieters**	Achterin zijn **gieters** verstopt
		Het meisje wil deze **gieters**	Hij had over zijn **gieters** gedroomd
		Door de **gieters** stroomt water	
		Blauwe **gieters** waren uitverkocht	
		Gelukkig staan twee **gieters** buiten	

APPENDIX 1: STIMULI

5	**gondels**	In deze **gondels** zit je goed	Paarse **gondels** zijn zeldzaam
		Onder hun **gondels** zwemmen vissen	Groene **gondels** heb je in Giethoorn
		Hij vindt alle **gondels** leuk	Alle **gondels** varen snel weg
		Vier van zulke **gondels** varen weg	In de **gondels** liggen zachte kussens
		Er is genoeg plaats in **gondels**	
		Het lijken wel blauwe **gondels**	
		Hier zijn de nieuwe **gondels** al	
		Vandaag komen de **gondels** niet	
6	**hinde**	Een vogel zag die **hinde** knielen	Vrolijk kijkt één **hinde** ons aan
		s' Nachts gaat een stoere **hinde** op jacht	Een aardige **hinde** weet de weg
		Het hertje hield van haar **hinde**	Vandaag krijgt haar **hinde** een huis
		Samen vingen zij jouw **hinde**	De reus gaf de **hinde** wat brood
		Daar eet een **hinde** het gras.	
		De kleine **hinde** volgt het spoor	
		Naast een **hinde** loopt een geit	
		Voor de **hinde** gaat het lastig	
7	**hommels**	Een goede plek vinden **hommels** fijn	De kleine **hommels** staan op een tak
		Overal zie je hier **hommels** gaan	Dat is voor **hommels** erg prettig
		Deze **hommels** zijn niet graag binnen	Grote **hommels** vliegen in de lucht
		Alle **hommels** houden van bloemen	Er zijn meer **hommels** dan bijen
		De eekhoorn zwaait naar **hommels**	
		Elke bij ziet de **hommels**	
		Zulke blije **hommels** zijn uniek	
		Grote gele **hommels** brengen geluk	
8	**krekels**	Ik zag **krekels** in het gras	Vier vrolijke **krekels** zijn er al
		Zulke **krekels** maken veel lawaai	De man legt de **krekels** in zijn hand
		Onder de boom waren drie **krekels**	Van drop houden **krekels** veel
		Het waren grote groene **krekels**	Vandaag gaan de **krekels** naar huis
		In sprookjes kunnen **krekels** spreken	
		De zebra ziet vaak **krekels** dansen	
		De blije **krekels** zijn er al	
		Voor deze **krekels** pakt het goed uit	
9	**krokus**	Naast de **krokus** liep een mier	Net naast deze **krokus** ligt wat
		Op een **krokus** lag nog sneeuw	De mooiste soort **krokus** is oud

		De dame zag deze **krokus**	Achter elke **krokus** ligt een knikker
		In het gras stond weer een **krokus**	De grotere **krokus** is mooier
		Onder de gele **krokus** groeit mos	
		Lang stond de roze **krokus** alleen	
		Een kleine **krokus** had blaadjes	
		De paarse **krokus** was mooi	
10	**lener**	Dan wil mijn **lener** wel betalen	Op een **lener** scheen de zon
		Een knappe **lener** loopt voorop	Elke **lener** krijgt vier boeken
		De pachter ging naar de **lener**	Elke **lener** hoopt op geluk
		Daar loopt een rustige **lener**	Aan haar **lener** lag het niet
		De wens van de **lener** werd verhoord	
		De dappere **lener** viert feest	
		Veel krijgt de kleine **lener** niet	
		Gisteren viel een **lener** van de trap	
11	**mammoet**	Vroeger was een **mammoet** eng	Niet één **mammoet** bleef thuis
		Spreken kon mijn **mammoet** niet.	Van haar **mammoet** is niets bekend
		Een grote **mammoet** was jarig	Door de **mammoet** wordt gejaagd
		De jonge **mammoet** gaat op jacht	Op die **mammoet** zit veel haar
		Lang geleden leefde de **mammoet**	
		Een leeuw past drie keer in jouw **mammoet**	
		De regen maakt deze **mammoet** nat	
		Het museum heeft een **mammoet** in huis	
12	**monnik**	Elke dag bidt een **monnik** veel	De mug wil geen **monnik** spreken
		Iedereen vroeg hun **monnik** om raad	Het huis van de **monnik** was mooi
		Deze **monnik** staat in de zon	Morgen gaat hun **monnik** op reis
		Aan de **monnik** is niets te zien	De tuin van jouw **monnik** is netjes
		Het was een grappige **monnik**	
		Niets is te veel voor die **monnik**	
		Volgens één **monnik** kwam alles goed	
		Een strenge **monnik** draagt een habijt	
13	**mosterd**	De slager verkoopt **mosterd** aan hem	Hij spaart **mosterd** uit Frankrijk
		Een kroket met veel **mosterd** is goed	Ierse **mosterd** is erg lekker
		Zij zocht naar de **mosterd**	Franse **mosterd** valt vaak tegen
		Hij lust echt geen **mosterd**	Grove **mosterd** staat op tafel

		De nieuwe **mosterd** is te zuur	
		De beste **mosterd** komt uit het noorden	
		Het meisje wil deze **mosterd** niet	
		Deze bijzondere **mosterd** loopt storm	
14	**otters**	Witte **otters** waren er niet	Verbaasd liepen er **otters** weg
		Boze **otters** kruipen op de grond	Van slapen hielden **otters** het meest
		Vlug gaan de **otters** er uit	Iedereen zag de **otters** zwemmen
		De kleine **otters** zwommen graag	De gorilla wil **otters** zien
		De jongen hield van zijn **otters**	
		Dit zijn de andere **otters**	
		De man hield drie **otters** vast	
		Nu zijn alle **otters** verdwenen	
15	**pelgrims**	De oude **pelgrims** slapen diep	Tien weken zijn de **pelgrims** weg
		Die Ierse **pelgrims** lopen lang	Van lopen houden **pelgrims** ook
		Fietsen vinden **pelgrims** leuk	Met veel lof zijn de **pelgrims** onthaald
		Altijd gaan er **pelgrims** van huis	De langzame **pelgrims** wisten alles
		Het klooster zoekt nog twee **pelgrims**	
		Dat komt goed uit voor die **pelgrims**	
		Deze **pelgrims** groeten de boeren	
		Vrome **pelgrims** zijn al vertrokken	
16	**pudding**	Na een warme **pudding** drink ik melk	Zij krijgt **pudding** na het eten
		De juf wil graag **pudding** als toetje	Deze **pudding** is net gemaakt
		In de koelkast wordt **pudding** koud	Gele **pudding** is warm beter
		Morgen zal er ook **pudding** zijn	Bij een **pudding** hoort slagroom
		Bovenaan zijn lijstje staat **pudding**	
		Er zit geen suiker in de **pudding**	
		Lekkere **pudding** is snel gemaakt	
		De beste **pudding** bevat vruchtjes	
17	**ronde**	De bloemist is geen **ronde** verder.	Over zijn **ronde** hoor je hem niet
		Voor de vrouw is de **ronde** lang	Niet elke **ronde** is gelijk
		Elke dag loopt hij zijn **ronde**	Hij wil een **ronde** schaatsen
		Zo zien jullie graag mijn **ronde**	De laatste **ronde** wint de rups
		Deze **ronde** was moeilijk	
		Vaak een **ronde** lopen is goed	

		De klassieke **ronde** is bekend	
		Na iedere **ronde** was er rust	
18	**sitar**	Nu zie je mijn **sitar** niet meer	De dienaar legt haar **sitar** weg
		Daar kun je hun **sitar** horen	De bijzondere **sitar** werd verkocht
		Zo speelt de **sitar** zijn spel	Op tafel werd een **sitar** gelegd
		Hier is een **sitar** te koop	De kooi heeft naast de **sitar** gestaan
		De muzikant pakt snel zijn **sitar**	
		Dat is een bijzondere **sitar**	
		Met je **sitar** maak je muziek	
		Op jouw **sitar** zitten drie snaren	
19	**sultan**	De slaaf gaf zijn **sultan** gelijk.	De spin zwaaide haar **sultan** uit
		Dan pas gaat een **sultan** verder.	IJverig zoekt jouw **sultan** zijn kat
		Voor de **sultan** is eten gemaakt	Overdag rust mijn **sultan** goed uit
		Onze **sultan** reist met een kameel	Een belangrijke **sultan** heeft macht
		Met straffe hand regeert de **sultan**	
		In koele schaduw stond een **sultan**	
		Hij laat die **sultan** aan het woord	
		De nieuwe **sultan** is jarig	
20	**zwaluw**	Overal kom je haar **zwaluw** tegen	De kleine **zwaluw** was hem gevlogen
		In de lucht zie je een **zwaluw** gaan	Er was één **zwaluw** bij de sluis
		Hij kijkt op naar mijn **zwaluw**	Men ziet geen **zwaluw** in het bos
		Zijn vrouw wacht op haar **zwaluw**	Een vroege **zwaluw** staat snel op.
		Vandaag vloog de **zwaluw** weg	
		Een gestreepte **zwaluw** is zeldzaam	
		Naast de **zwaluw** vliegt een bij	
		Voor jouw **zwaluw** is er plek	

APPENDIX 1D: DESIGN FROM EXPERIMENT 4.2

Trial	Visual stimulus	Auditory stimulus
TRAINING		
1	car_1	kijk een auto
2	*tiek*	dit is een tiek…tiek…een tiek…tiek…zie je de tiek?
3	dog_1	kijk een hond
4	*paas*	dat is mooi…kijk…mooi he…ja…zie je dat?
5	*tiek*	dit is een tiek…tiek…een tiek…tiek…zie je de tiek?
6	*paas*	dat is mooi…kijk…mooi he…ja…zie je dat?
	Attention grabber	
7	$ball_1$	kijk een bal
8	*paas*	dat is mooi…kijk…mooi he…ja…zie je dat?
9	*tiek*	dit is een tiek…tiek…een tiek…tiek…zie je de tiek?
10	cow_1	kijk een koe
11	*tiek*	dit is een tiek…tiek…een tiek…tiek…zie je de tiek?
12	*paas*	dat is mooi…kijk…mooi he…ja…zie je dat?
	Attention grabber	
13	$baby_1$	kijk een baby
14	*paas*	dat is mooi…kijk…mooi he…ja…zie je dat?
15	*tiek*	dit is een tiek…tiek…een tiek…tiek…zie je de tiek?
16	*paas*	dat is mooi…kijk…mooi he…ja…zie je dat?
17	cat_1	kijk een poes
18	*tiek*	dit is een tiek…tiek…een tiek…tiek…zie je de tiek?
	Attention grabber	
TEST		
1	$ball_1$ - car_1	waar is de auto?... auto!
2	$baby_1$ – cat_1	zie je de baby?... baby!
3	*paas – tiek*	kijk naar de tiek!...tiek!
4	*tiek - paas*	zie je de paas?...paas!
	Attention grabber	
5	*tiek - paas*	waar is de tiek?...tiek!
6	cow_1 - dog_1	kijk naar de hond!...hond!
7	*paas – tiek*	waar is de paas?...paas!
	Attention grabber	
8	cat_1 – $baby_1$	kijk naar de poes!...poes!
9	*tiek – paas*	waar is de tiek?...tiek!
10	dog_1 – cow_1	kijk naar de koe!...koe!
11	*paas – tiek*	zie je de tiek?...tiek!
	Attention grabber	
12	*tiek – paas*	kijk naar de paas!...paas!
13	car_1 - $ball_1$	zie je de bal?...bal!

14	*paas – tiek*	waar is de paas?...paas!
	Attention grabber	
15	*tiek – paas*	zie je de paas?...paas!
16	cow_2 – dog_2	waar is de koe?...koe!
17	*paas – tiek*	kijk naar de tiek!...tiek!
	Attention grabber	
18	*tiek – paas*	zie je de tiek?...tiek!
19	cat_2 - $baby_2$	waar is de baby?...baby!
20	*paas – tiek*	kijk naar de paas!...paas!
21	$ball_2$ - car_2	waar is de bal?...bal!
	Attention grabber	
22	*paas – tiek*	waar is de tiek?...tiek!
23	dog_2 - cow_2	zie je de hond?...hond!
24	*tiek – paas*	kijk naar de paas!...paas!
	Attention grabber	
25	*paas – tiek*	zie je de paas?...paas!
26	$baby_2$ – cat_2	waar is de poes?...poes!
27	*tiek – paas*	zie je de tiek?...tiek!
28	car_2 – $ball_2$	kijk naar de auto!...auto!
	Attention grabber	
29	*tiek – paas*	waar is de paas?...paas!
30	$baby_3$ – cat_3	kijk naar de baby!...baby!
31	*paas – tiek*	zie je de tiek?...tiek!
32	dog_3 - cow_3	waar is de hond?...hond!
	Attention grabber	
33	*paas – tiek*	kijk naar de paas!...paas!
34	$ball_3$ - car_3	zie je de auto?...auto!
35	*tiek – paas*	kijk naar de tiek!...tiek!
	Attention grabber	
36	car_3 - $ball_3$	kijk naar de bal!...bal!
37	*paas – tiek*	zie je de paas?...paas!
38	*tiek – paas*	waar is de tiek?...tiek!
	Attention grabber	
39	cow_3 - dog_3	zie je de koe?...koe!
40	*paas – tiek*	kijk naar de tiek!...tiek!
41	cat_3 - $baby_3$	zie je de poes?...poes!
42	*tiek – paas*	waar is de paas?...paas!

Note: visual stimuli during test: first mentioned object was on the left, second on the right. Numbers in subscript correspond to specific visual exemplars of known stimuli.

APPENDIX 1E: THE DUTCH VERSION OF THE 'SPEECH AND LANGUAGE ASSESSMENT SCALE'

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RADBOUD UNIVERSITEIT NIJMEGEN
Faculteit der Sociale Wetenschappen

TAALONTWIKKELING – Peuters & Kleuters
Beoordeling van Taal- & Spraakvaardigheden

Naam van kind: Geboortedatum van kind:
Ingevuld door: Relatie met betrekking tot het kind:
Datum:

Beoordeelt u alstublieft de taalvaardigheden en sociale vaardigheden van uw kind in vergelijking met andere kinderen van zijn of haar leeftijd.

Opmerkingen:

1. Mijn kind kan op een juiste manier **vragen te stellen** is:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

2. Mijn kind kan op een passende manier **vragen beantwoorden**:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

3. Mijn kind kan **begrijpen** wat anderen tegen hem of haar zeggen:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

4. Mijn kind kan **zinnen duidelijk genoeg zeggen** om voor onbekenden verstaanbaar te zijn:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

5. Het **aantal woorden** dat mijn kind kent is: **Opmerkingen:**

1	2	3	4	5	6	7
erg weinig			gemiddeld voor zijn/haar leeftijd			erg veel

6. Mijn kind **gebruikt** zijn of haar woorden op een correcte wijze:

1	2	3	4	5	6	7
erg weinig			gemiddeld voor zijn/haar leeftijd			erg veel

7. Mijn kind kan aan anderen goed **duidelijk maken** wat hij of zij bedoelt, terwijl hij of zij aan het praten is:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

8. Mijn kind kan **aanwijzingen begrijpen** die aan hem of haar gericht zijn:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

9. Mijn kind kan **aanwijzingen opvolgen**:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

10. Mijn kind **gebruikt de juiste woorden** in de juiste situatie:

1	2	3	4	5	6	7
erg weinig			gemiddeld voor zijn/haar leeftijd			erg veel

11. Mijn kind kan **door het te zeggen** krijgen wat hij of zij wil:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

12. Mijn kind kan **een gesprek beginnen**, of beginnen met kletsen met andere kinderen:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

13. Mijn kind kan **een gesprek gaande houden** met andere kinderen:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

14. De **gemiddelde lengte van de zinnen** die mijn kind maakt is: **<u>Opmerkingen:</u>**

1	2	3	4	5	6	7
erg kort			gemiddeld voor zijn/haar leeftijd			erg lang

15. Mijn kind kan **'volwassen' zinnen maken**:

1	2	3	4	5	6	7
erg weinig			gemiddeld voor zijn/haar leeftijd			erg veel

16. Mijn kind kan duidelijk **de juiste klanken produceren** in losse woorden:

1	2	3	4	5	6	7
erg slecht			gemiddeld voor zijn/haar leeftijd			erg goed

17. Mijn kind is **zich bewust** van de verschillende manieren waarop mensen zich gedragen, spreken, kleden, etc. :

1	2	3	4	5	6	7
erg weinig			gemiddeld voor zijn/haar leeftijd			erg veel

18. Mijn kind **spreekt** meestal:

1	2	3	4	5	6	7
te zacht			gemiddeld voor zijn/haar leeftijd			te hard

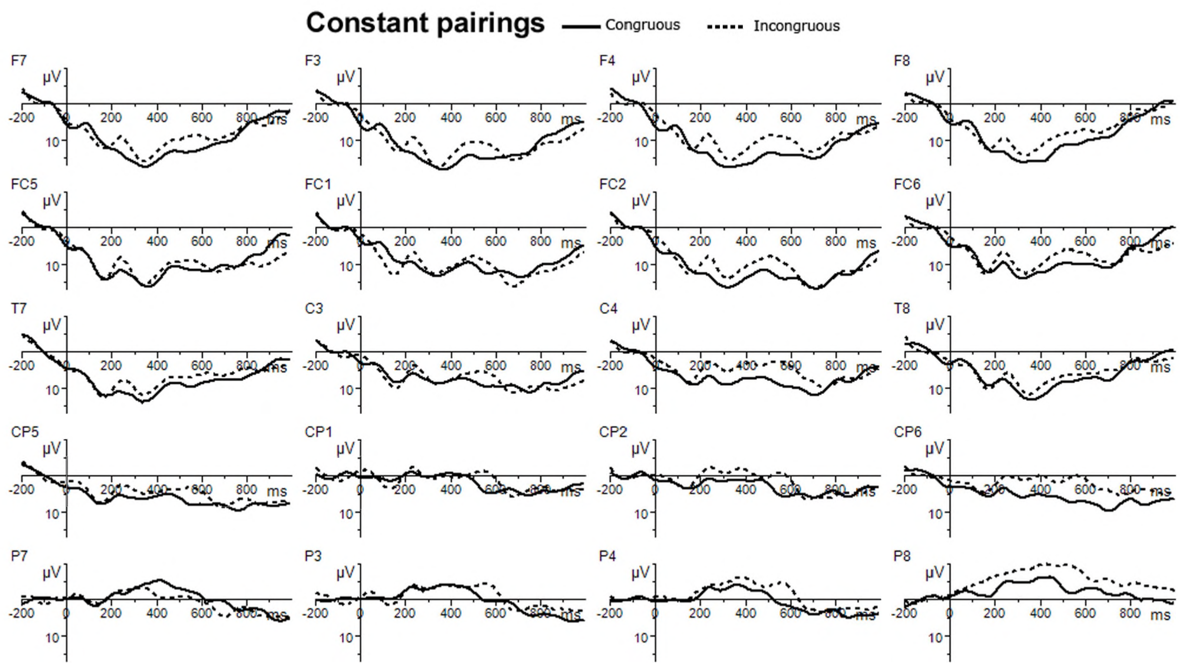
19. Mijn kind **spreekt** meestal:

1	2	3	4	5	6	7
te weinig			gemiddeld voor zijn/haar leeftijd			te veel

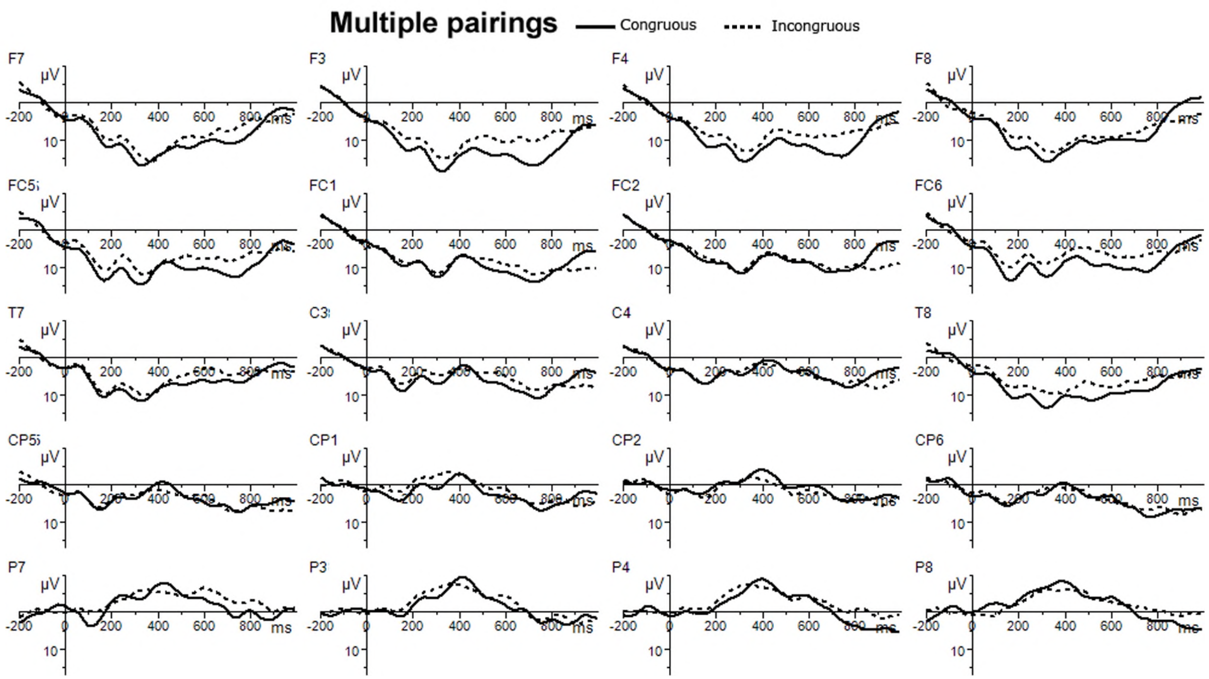
Dank u wel voor het invullen van deze enquête!

Note: Hadley & Rice (1993) calculated the wsubscales as follows: 1-Assertiveness (averaged over items 1,11,12); 2- Responsiveness (averaged over items 2, 13); 3-Semantics (averaged over items 5,6,10); 4-Syntax (averaged over items 14,15); 5-Articulation (averaged over items 4,7, 16); and 6-Talkativeness (item 19). The remaining items (3, 8, 9, 17 and 18) were not taken into account.

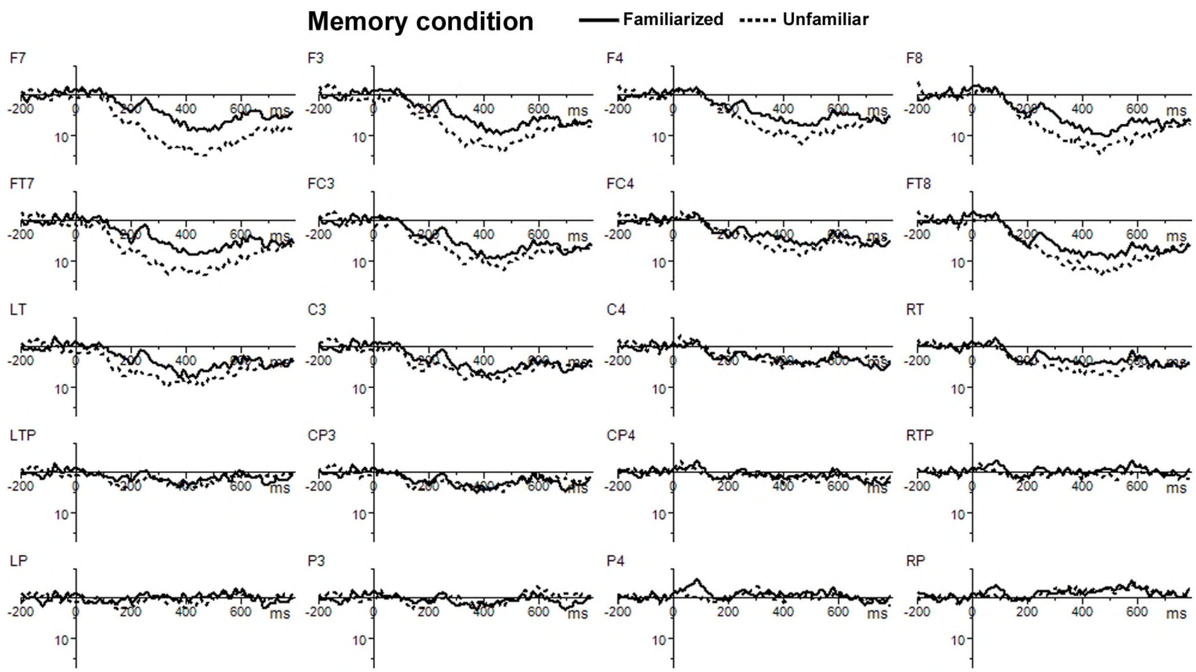
APPENDIX 2: ADDITIONAL ERP FIGURES



APPENDIX 2A. Results from the test phase in Chapter 2 for constant pairings: *Grand average waveforms on 20 scalp electrodes, time-locked to the onset of words (solid line: congruous words, dashed line: incongruous words).*

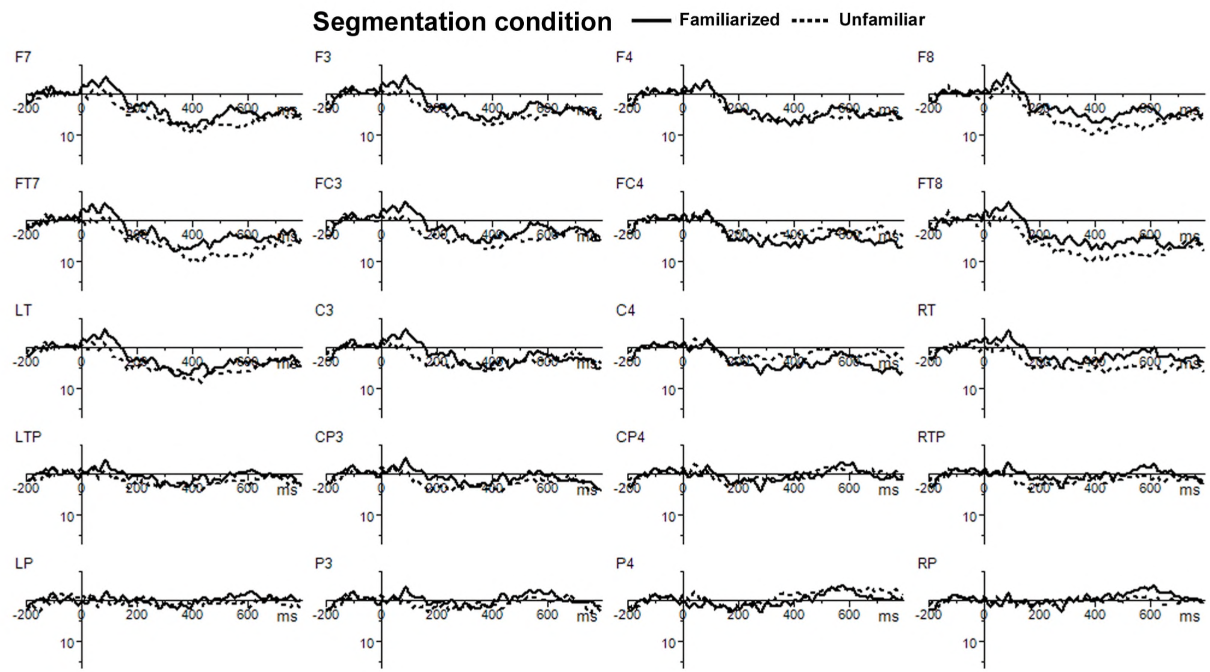


APPENDIX 2B. Results from the test phase in Chapter 2 for multiple pairings : *Grand average waveforms on 20 scalp electrodes, time-locked to the onset of words (with additional 8Hz low-pass filter for illustrative purposes; solid line: congruous words, dashed line: incongruous words).*



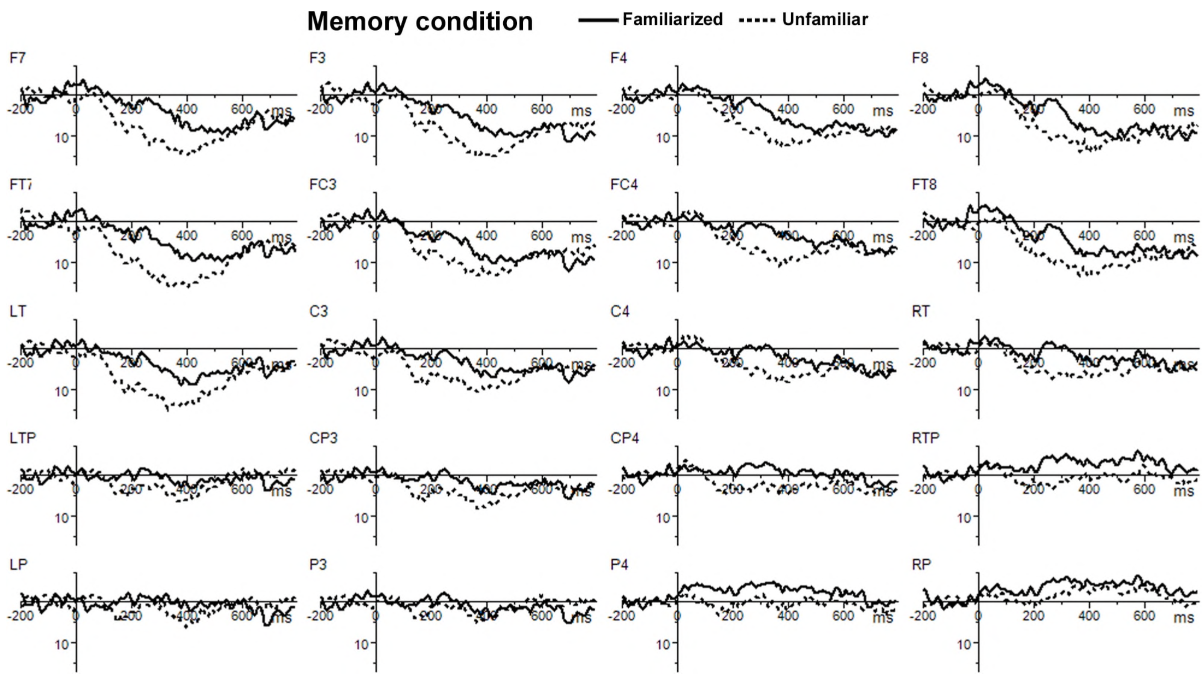
APPENDIX 2C. Results from the memory condition in Chapter 3 for all subjects :

Grand average waveforms on 20 scalp electrodes (solid line: familiarized words, dashed line: unfamiliar words).

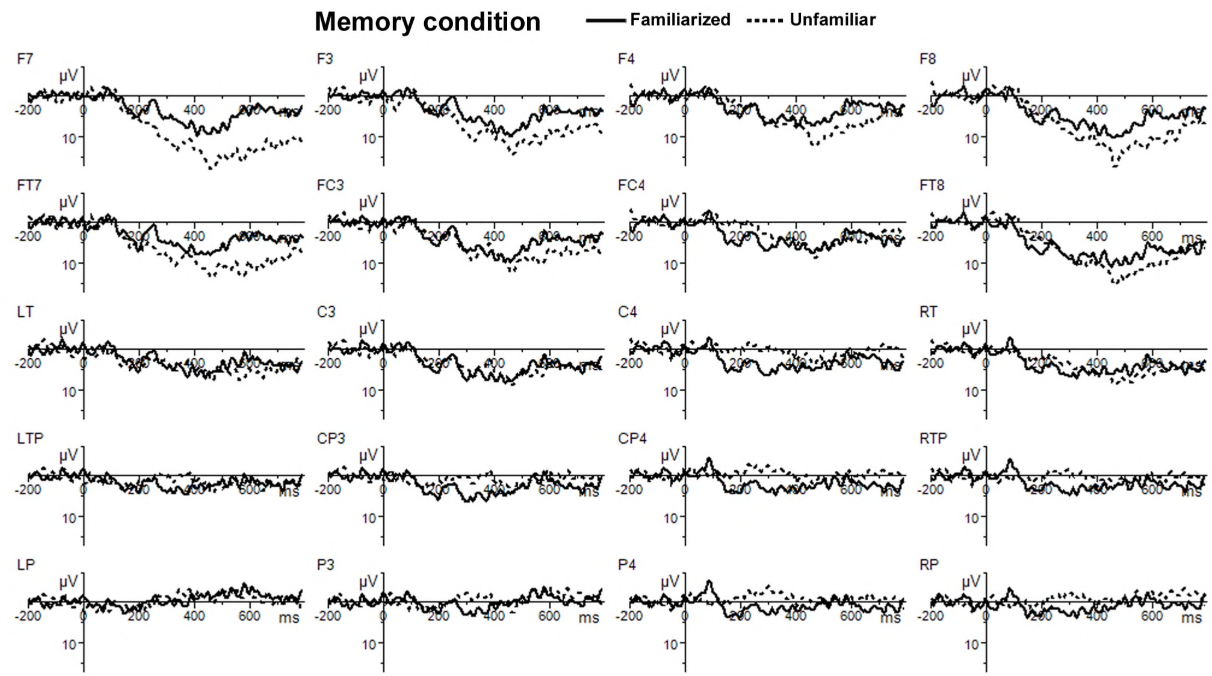


APPENDIX 2D. Results from the segmentation condition in Chapter 3 for all subjects :

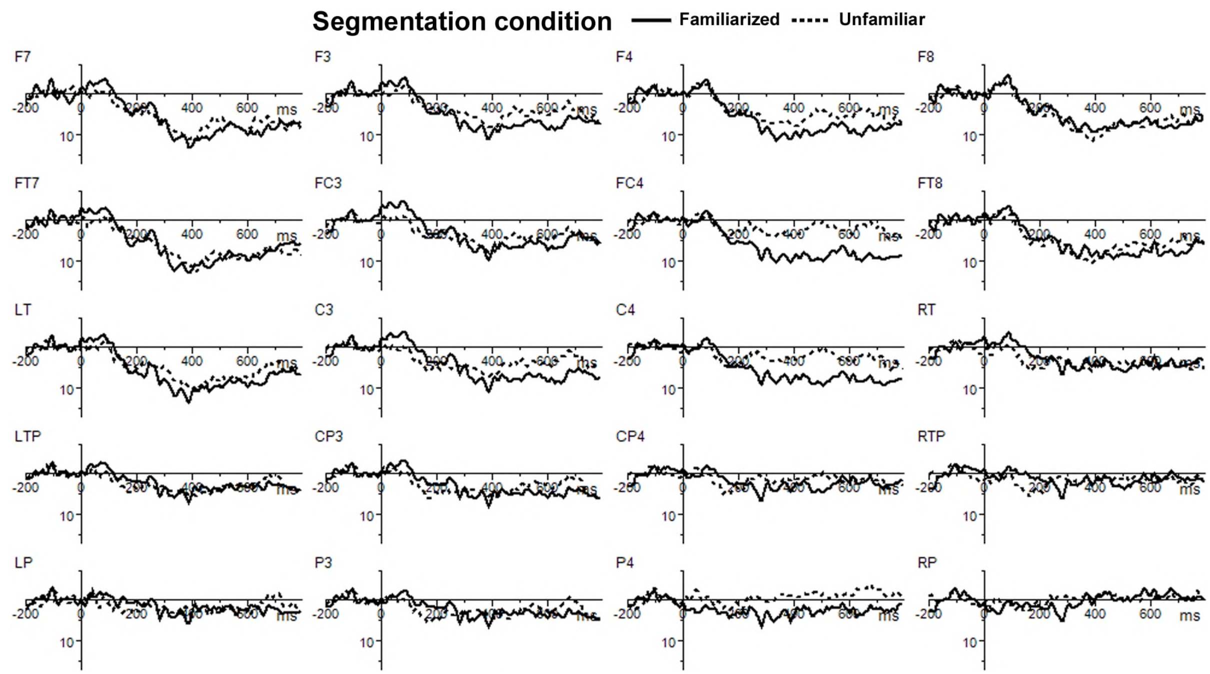
Grand average waveforms on 20 scalp electrodes (solid line: familiarized words, dashed line: unfamiliar words).



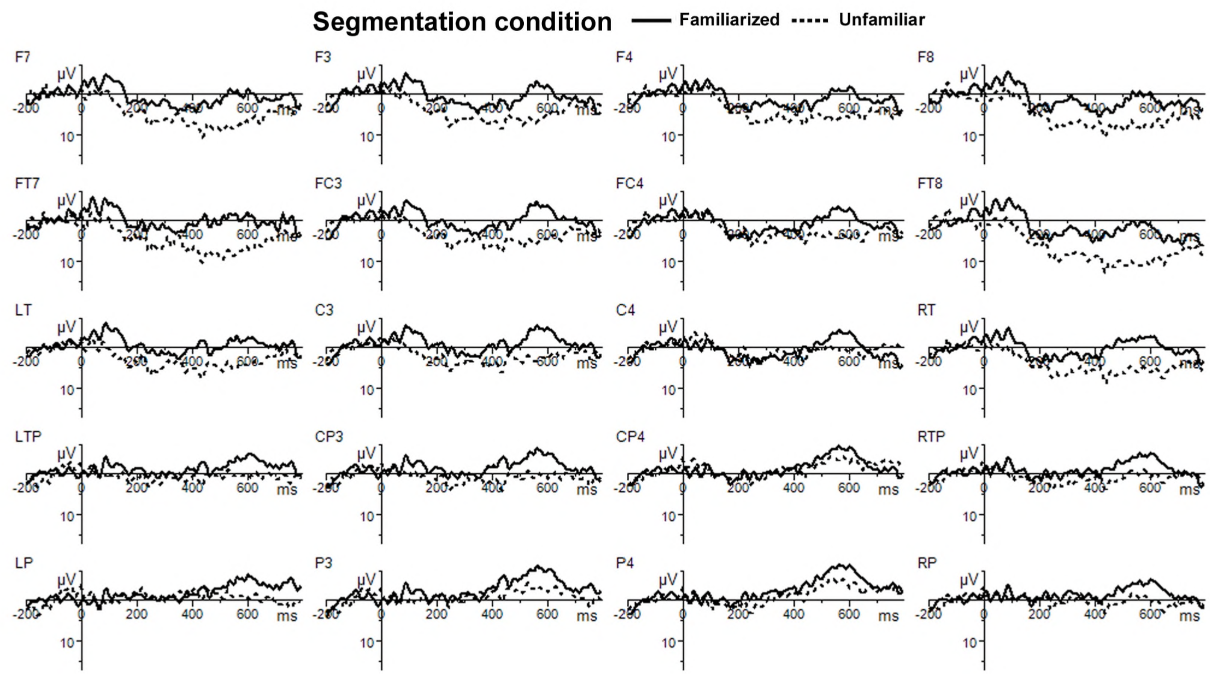
APPENDIX 2E. Results from the memory condition in Chapter 3 for the Lower Vocabulary group: *Grand average waveforms on 20 scalp electrodes (solid line: familiarized words, dashed line: unfamiliar words).*



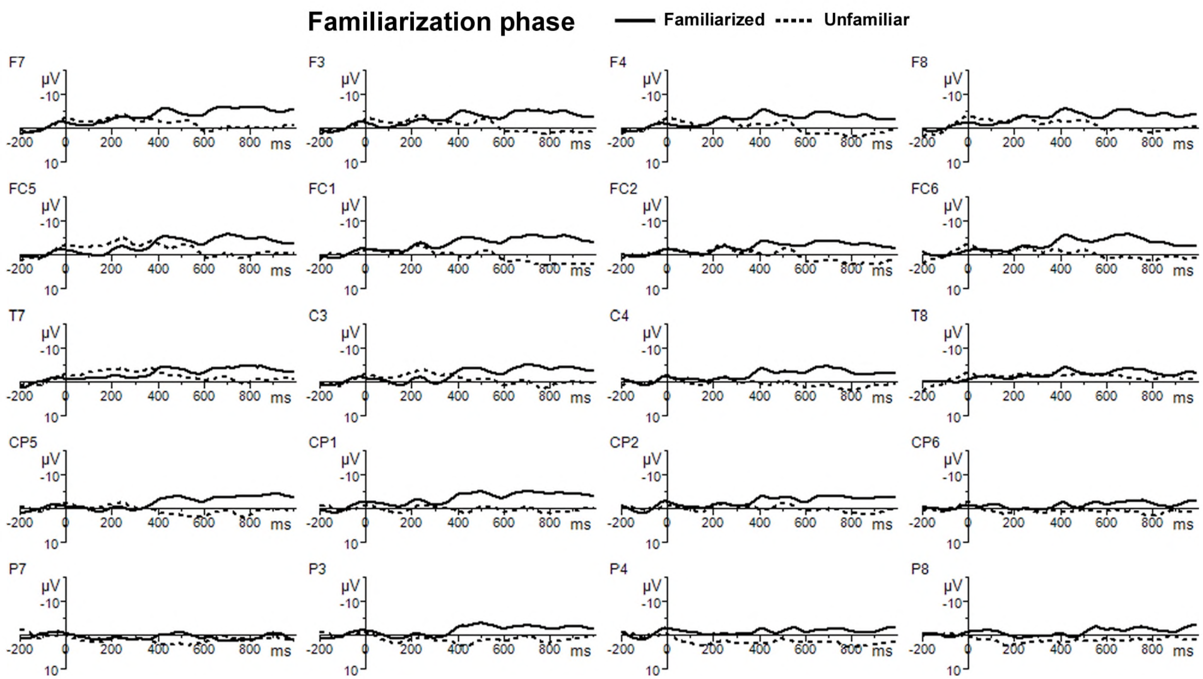
APPENDIX 2F. Results from the memory condition in Chapter 3 for the Higher Vocabulary group: *Grand average waveforms on 20 scalp electrodes (solid line: familiarized words, dashed line: unfamiliar words).*



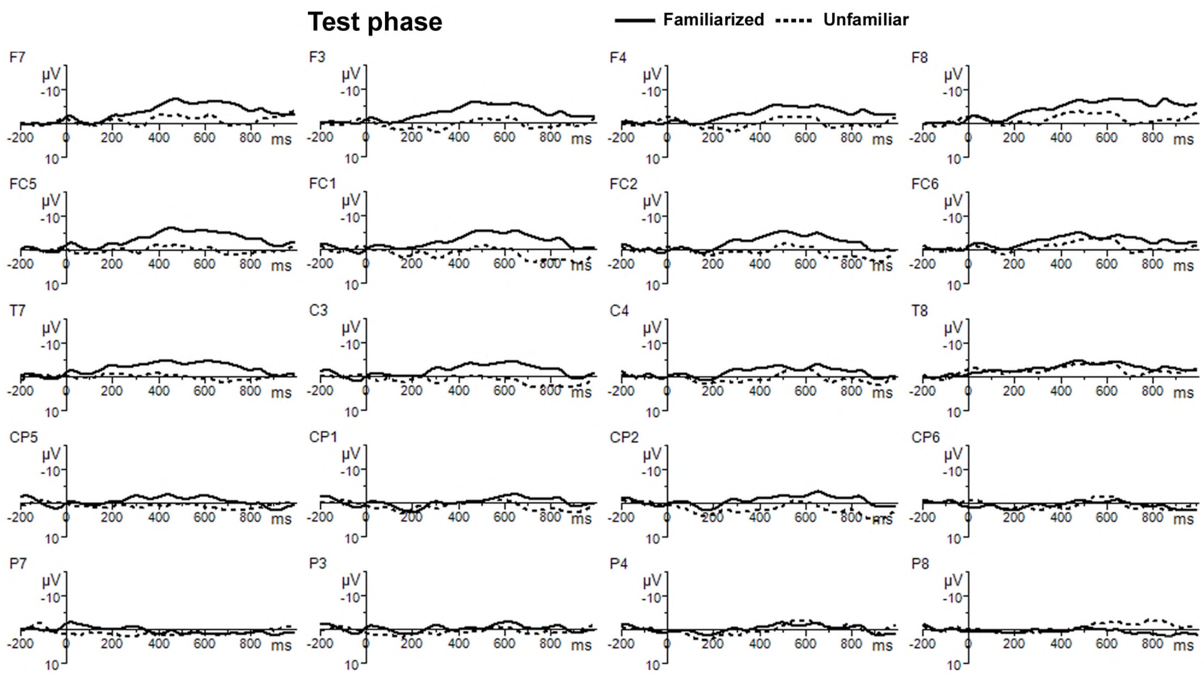
APPENDIX 2G. Results from the segmentation condition in Chapter 3 for the Lower Vocabulary group: *Grand average waveforms on 20 scalp electrodes (solid line: familiarized words, dashed line: unfamiliar words).*



APPENDIX 2H. Results from the segmentation condition in Chapter 3 for the Higher Vocabulary group: *Grand average waveforms on 20 scalp electrodes (solid line: familiarized words, dashed line: unfamiliar words).*



APPENDIX 2I. Results from the familiarization phase in Chapter 4 : *Grand average waveforms on 20 scalp electrodes (solid line: last two tokens, dashed line: first two tokens; with additional 8 Hz low-pass filter).*



APPENDIX 2J. Results from the test phase in Chapter 4: *Grand average waveforms on 20 scalp electrodes (solid line: familiarized words, dashed line: unfamiliar words; with additional 8 Hz low-pass filter).*

APPENDIX 3: SUPPORTING TABLES

APPENDIX 3A: SUPPORTING TABLES OF CHAPTER 2

Supporting Table 1

Behavioral results: number of trials a child is looking away

Supporting Table 1a

ANOVA on mean number of trials a child is looking away in the training phase

source	df	F	MSE	p
ANOVA: Repetition (2) x Type of pairing (2)				
Repetition	1,19	3.67	12.8	.07
Type of pairing	1,19	1.64	4.05	.22
Rep. x Pairing	1,19	0.46	0.80	.51

Supporting Table 1b

ANOVA on mean number of trials a child is looking away in the test phase

source	df	F	MSE	p
ANOVA: Congruity (2) x Type of pairing (2)				
Congruity	1,19	0.75	0.80	.40
Type of pairing	1,19	0.050	0.80	.83
Congr. x Pairing	1,19	0.026	0.50	.87

Supporting Table 1c

ANOVA on mean number of trials a child is looking away during the experiment

source	df	F	MSE	p
ANOVA: Phase of experiment (2) x Type of pairing (2)				
Phase of experiment	1,19	6.15	135.2	.023*
Type of pairing	1,19	0.49	8.45	.49
Phase. x Pairing	1,19	0.064	1.25	.80

*p<.05

Supporting Table 2

ANOVA on mean ERP amplitude in the 300 to 750 ms latency range time-locked to the onset of pictures in the training phase

source	df	F	MSE	p
ANOVA: Repetition (2) x Type of pairing (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Repetition	1,19	12.64	10539.9	.002**
Type of pairing	1,19	8.21	5063.5	.010*
Rep. x Pairing	1,19	1.76	1565.5	.20
Rep. x Ant/Post	1,19	12.0	1698.9	.003**
Pairing x Ant/Post	1,19	5.08	972.0	.036

Note. Rep. =Repetition; Ant/Post = Anterior/Posterior

*p<.05 **p<.01

Supporting Table 3

ANOVAs on mean ERP amplitude in the latency window 300-600 ms time-locked to the onset of words in the training phase.

Supporting Table 3a

ANOVA on mean ERP amplitude in the 300 to 600 ms latency range time-locked to the onset of words in the training phase, for the first three pairings versus last three pairings.

source	df	F	MSE	p
ANOVA: Repetition (2) x Type of pairing (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Repetition	1,19	36.5	9374.6	<.001***
Type of pairing	1,19	0.23	299.3	.64
Rep. x Pairing	1,19	1.48	472.8	.24
Rep. x Ant/Post	1,19	42.1	2476.4	<001***
Pairing x Ant/Post	1,19	1.56	534.2	.23

Note. Rep. =Repetition; Ant/Post = Anterior/Posterior

*p<.05 **p<.01 ***<.001

Supporting Table 3b

ANOVA on mean ERP amplitude in the 300 to 600 ms latency range time-locked to the onset of words in the training phase, for the first two, medial two and last two pairings (collapsed over training types)

source	df	F	MSE	p
ANOVA: Repetition (3) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Repetition	2,38	10.9	4263.6	<.001***
Rep. x Ant/Post	2,38	14.4	717.8	<.001***

Note. Rep. =Repetition; Ant/Post = Anterior/Posterior

*p<.05 **p<.01 ***<.001

Supporting Table 4

ANOVAs on mean ERP amplitude in the latency windows 200-300, 300-400 and 400 to 600 ms latency range time-locked to the onset of words in the test phase

Supporting Table 4a 200-300 ms

source	df	F	MSE	p
ANOVA: Congruity (2) x Type of pairing (2) x Quadrant (4) x Electrode (5)				
Congruity	1,19	5.64	1680.7	.028*
Type of pairing	1,19	0.23	193.1	.63
Congr. x Pairing	1,19	0.17	120.4	.69
Congr. x Quadrant	3,57	0.97	64.2	.40
Pairing x Quadrant	3,57	1.10	82.1	.35
Congr. x Pairing x Quadrant	3,57	0.35	23.0	.76

Note. Congr. = Congruity; *p<.05 **p<.01

Supporting Table 4b 300-400ms

source	df	F	MSE	p
ANOVA: Congruity (2) x Type of pairing (2) x Quadrant (4) x Electrode (5)				
Congruity	1,19	1.63	658.8	.22
Type of pairing	1,19	4.04	2156.7	.06
Congr. x Pairing	1,19	0.070	42.9	.79
Congr. x Quadrant	3,57	0.43	60.7	.68
Pairing x Quadrant	3,57	0.43	30.7	.74
Congr. x Pairing. x Quadrant	3,57	0.96	86.2	.41

Note. Congr. = Congruity; *p<.05 **p<.01

Supporting Table 4c 400-600 ms

source	df	F	MSE	p
ANOVA: Congruity (2) x Type of pairing (2) x Quadrant (4) x Electrode (5)				
Congruity	1,19	7.52	1554.9	.013*
Type of pairing	1,19	2.44	1089.4	.14
Congr. x Pairing	1,19	0.80	447.6	.38
Congr. x Quadrant	3,57	1.33	86.3	.28
Pairing x Quadrant	3,57	0.82	75.6	.49
Congr. x Pairing. x Quadrant	3,57	0.95	73.0	.41

Note. Congr. = Congruity; *p<.05 **p<.01

Supporting Table 5

Correlation coefficients matrix for the ERP measures (the Nc-effect on anterior electrodes, the word familiarity effect on anterior electrodes, and the N400-effect on posterior electrodes, all collapsing over type of pairings); and for the parental questionnaires (CDI, parental ratings).

	Measure	**1.**	**2.**	**3.**	**4.**	**5.**	**6.**	**7.**	**8.**
ERPs	**0.** Nc-effect	.10	- .39	-.07	-.06	.-06	.42	.10	-.05
	1. Word familiarity effect		-.24	.13	.10	.26	-.08	-.38	.29
	2. N400-effect			-.48*	-.45*	-.45*	-.34	.31	.08
CDI	**3.** CDI – All items understood				.63**	.99***	.13	.02	.37
	4. CDI – Words understood					.54*	.13	.04	.37
	5. CDI – Phrases understood						.03	-.19	.16
	6. CDI- Words produced							-.10	.24
Ratings	**7.** Visual Ratings								.12
	8. Words Ratings								

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

APPENDIX 3B: SUPPORTING TABLES OF CHAPTER 3

Supporting Table 1

ANOVA on mean ERP amplitude in the 200 to 650 ms latency range time-locked to words in the test phase of the memory condition.

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,27	4.72	1088.7	.039*
Fam. x Qua	3,81	2.43	190.5	.088
Fam. Per Quadrant				
Left Frontal	1,27	11.9	1009.9	.002**
Right Frontal	1,27	5.17	433.8	.031*
Left Posterior	1,27	0.47	44.2	.50
Right Posterior	1,27	0.30	45.5	.59

Note. Fam. =Familiarity; Qua = Quadrant
*p<.05 **p<.01 ***<.001

Supporting Table 2

ANOVAs on mean ERP amplitude in the latency windows 500-600 and 200-650 ms time-locked to target word onset in the segmentation condition.

Supporting Table 2a

500 to 600 ms time window

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,27	1.84	1076.9	.19
Fam. x Qua	3,81	0.57	47.7	.63
Fam. Per Quadrant				
Left Frontal	1,27	3.13	696.4	.09
Right Frontal	1,27	0.65	183.0	.43
Left Posterior	1,27	1.15	195.8	.29
Right Posterior	1,27	0.94	137.5	.34

Note. Fam. =Familiarity; Qua = Quadrant
*p<.05 **p<.01 ***<.001

Supporting Table 2b

200 to 650 ms time window

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,27	0.64	305.4	.43
Fam. x Qua	3,81	0.34	22.1	.76
Fam. Per Quadrant				
Left Frontal	1,27	0.64	305.4	.43
Right Frontal	1,27	1.29	214.2	.27
Left Posterior	1,27	0.12	26.9	.73
Right Posterior	1,27	062	86.8	.44

Note. Fam. =Familiarity; Qua = Quadrant
*p<.05 **p<.01 ***<.001

Supporting Table 3

ANOVAs on mean ERP amplitude in the 200-650 ms latency range time-locked to target word onset in the segmentation and memory conditions, with vocabulary group as between-subjects factor.

source	df	F	MSE	p
ANOVA: Familiarity (2) x Condition (2) x Quadrant (4) x Electrode (5) x Vocabulary Group (2)				
Familiarity	1,26	3.49	1273.6	.073
Fam. x Voc.Gr.	1,26	0.46	168.4	.50
Fam. x Cond.	1,26	0.43	120.4	.52
Fam. x Qua.	3,78	2.06	126.9	.12
Fam. x Cond. x Voc.Gr.	1,26	8.09	2249.2	.009**
Fam. x Cond. x Qua.	3,78	0.85	56.7	.46
Fam. Cond. x Voc.Gr x Qua.	3,78	0.40	26.4	.73
Cond.	1,26	1.13	676.2	.30
Cond. x Voc.Gr.	1,26	2.08	1240.5	.16

Note. Fam. =Familiarity; Voc.Gr = Vocabulary Group; Cond. = Familiarization condition; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 4

ANOVAs on mean ERP amplitude in the 200-650 ms latency range time-locked to target word onset for infants with Lower Vocabularies.

Supporting Table 4a

Including the memory as well as segmentation conditions

source	df	F	MSE	p
ANOVA: Familiarity (2) x Condition (2) x Quadrant (4) x Electrode (5) x Vocabulary Group (2)				
Familiarity	1,13	0.54	257.9	.48
Fam. x Cond.	1,13	7.12	1705.3	.019*
Fam. x Qua.	3,39	0.096	8.59	.93
Fam. x Cond. *Qua.	3,39	0.71	47.7	.55
Separate per Quadrant				
Left frontal	1,13	0.84	124.7	.38
Right frontal	1,13	0.12	25.8	.74
Left posterior	1,13	0.44	54.0	.52
Right posterior	1,13	0.37	72.6	.55

Note. Fam. =Familiarity; Cond. = Familiarization condition; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 4b

Separate for the memory condition

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,13	6.96	1644.8	.020*
Fam. x Qua.	3,39	0.34	34.2	.73
Separate per Quadrant				
Left frontal	1,13	4.76	598.1	.048*
Right frontal	1,13	1.38	178.5	.26
Left posterior	1,13	8.39	539.5	.013*
Right posterior	1,13	2.93	402.9	.11

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 4c

Separate for the segmentation condition

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,13	0.66	318.4	.43
Fam. x Qua.	3,39	0.49	32.1	.68
Separate per Quadrant				
Left frontal	1,13	0.45	75.0	.51
Right frontal	1,13	0.070	8.77	.80
Left posterior	1,13	1.07	257.4	.32
Right posterior	1,13	0.49	64.4	.50

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 5

ANOVAs on mean ERP amplitude in the 200-650 ms latency range time-locked to target word onset for infants with Higher Vocabularies.

Supporting Table 5a

Including the memory as well as segmentation conditions

source	df	F	MSE	p
ANOVA: Familiarity (2) x Condition (2) x Quadrant (4) x Electrode (5) x Vocabulary Group (2)				
Familiarity	1,13	4.79	1184.0	.047*
Fam. x Cond.	1,13	2.10	664.4	.17
Fam. x Qua.	3,39	4.30	216.5	.013*
Fam. x Cond. *Qua.	3,39	0.52	34.4	.63
Separate per Quadrant				
Left frontal	1,13	15.4	1241.1	.002**
Right frontal	1,13	3.99	438.4	.067
Left posterior	1,13	0.74	74.2	.40
Right posterior	1,13	0.18	16.3	.68

Note. Fam. =Familiarity; Cond. = Familiarization condition; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 5b

Separate for the memory condition

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,13	0.19	32.3	.67
Fam. x Qua.	3,39	3.76	216.3	.025*
Separate per Quadrant				
Left frontal	1,13	8.50	418.8	.012*
Right frontal	1,13	0.31	15.6	.59
Left posterior	1,13	0.39	38.8	.54
Right posterior	1,13	0.77	110.9	.40

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 5c

Separate for the segmentation condition

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,13	4.94	1811.1	.045*
Fam. x Qua.	3,39	0.81	46.6	.48
Separate per Quadrant				
Left frontal	1,13	7.01	861.9	.020*
Right frontal	1,13	1.74	260.5	.21
Left posterior	1,13	3.11	546.7	.10
Right posterior	1,13	3.86	263.5	.071

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 6

ANOVAs on mean ERP amplitude in the 200-500 ms latency range time-locked to target word onset in the memory condition, for infants with Lower Vocabularies and Higher Vocabularies, respectively.

Supporting Table 6a

For infants with Lower Vocabularies

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,13	18.8	2846.1	.001**
Fam. x Qua.	3,39	0.48	67.3	.61
Separate per Quadrant				
Left frontal	1,13	11.9	1151.5	.004**
Right frontal	1,13	20.4	890.0	.001**
Left posterior	1,13	3.04	398.0	.11
Right posterior	1,13	3.91	528.2	.07

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 6b

For infants with Higher Vocabularies

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,13	0.062	15.8	.81
Fam. x Qua.	3,39	3.12	189.6	.049*
Separate per Quadrant				
Left frontal	1,13	2.76	198.1	.12
Right frontal	1,13	0.004	0.39	.95
Left posterior	1,13	0.79	62.9	.59
Right posterior	1,13	1.44	216.6	.25
Electrodes F3, F7, FT7, FC3				
Familiarity	1,13	5.17	287.6	.041*

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 7

ANOVAs on mean ERP amplitude in the 500-650 ms latency range time-locked to target word onset in the memory condition, for infants with Lower Vocabularies and Higher Vocabularies, respectively.

Supporting Table 7a

For infants with Lower Vocabularies

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,13	0.39	224.1	.54
Fam. x Qua.	3, 39	0.46	36.64	.71
Separate per Quadrant				
Left frontal	1,13	0.11	30.3	.75
Right frontal	1,13	0.57	100.3	.47
Left posterior	1,13	<.001	0.031	.99
Right posterior	1,13	1.05	203.1	.33

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 7b

For infants with Higher Vocabularies

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,13	2.05	689.8	.18
Fam. x Qua.	3, 39	3.42	334.8	.042*
Separate per Quadrant				
Left frontal	1,13	12.09	1104.9	.004**
Right frontal	1,13	1.43	304.2	.25
Left posterior	1,13	0.23	16.0	.64
Right posterior	1,13	0.026	4.63	.88

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

APPENDIX 3C: SUPPORTING TABLES OF CHAPTER 4

Supporting Table 1

ANOVA on mean ERP amplitude in the 350 to 500 ms latency range time-locked to the first two tokens versus last two tokens of target words in the familiarization phase.

source	df	F	MSE	p
ANOVA: Familiarity (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Familiarity	1,27	4.82	2450.6	.037*
Fam. x Hemi	1,27	0.027	1.98	.87
Fam. x Ant/Post	1,27	0.63	52.2	.44
Fam. x Electrode	4,108	1.18	33.7	.32
Fam. x Hemi. x Ant/Post.	1,27	1.77	46.9	.20

Note. Fam. =Familiarity; Hemi = Hemisphere; Ant/Post = Anterior/Posterior
*p<.05 **p<.01 ***<.001

Supporting Table 2

Pair-wise Comparisons on mean ERP amplitude over 20 lateral electrodes in the 350 to 500 ms latency range time-locked to the first two tokens (1&2) versus the third and fourth versus the fifth and sixth versus the last two (seventh and eighth) tokens of target words in the familiarization phase.

Pairing	Comparisons	Mean Difference	95% C.I. for difference	T(27)	p
1&2	3&4	0.50	-2.99 - +4.00	0.30	.77
	5&6	1.86	-1.27 - +4.99	1.22	.23
	7&8	2.96	+.19 - +5.72	2.20	.037*

Note. *p<.05

Supporting Table 3

ANOVA on mean ERP amplitude in the 600 to 900 ms latency range time-locked to the first two tokens versus last two tokens of target words in the familiarization phase.

source	df	F	MSE	p
ANOVA: Familiarity (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Familiarity	1,27	10.8	5855.3	.003**
Fam. x Hemi	1,27	0.001	0.10	.97
Fam. x Ant/Post	1,27	4.56	595.3	.042*
Fam. x Electrode	4,108	1.44	49.0	.23
Fam. x Hemi x Ant/Post	1,27	0.013	0.52	.91
Separate for Anterior and Posterior electrodes				
Anterior	1,27	10.73	5092.2	.003**
Posterior	1,27	6.92	1358.3	.014*

Note. Fam. =Familiarity; Hemi = Hemisphere; Ant/Post = Anterior/Posterior
*p<.05 **p<.01 ***<.001

Supporting Table 4

ANOVA on mean ERP amplitude in the 220 to 500 ms latency range time-locked to familiarized versus unfamiliarized target words in the test phase.

source	df	F	MSE	p
ANOVA: Familiarity (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Familiarity	1,27	5.04	1736.1	.033*
Fam. x Hemi	1,27	0.30	14.32	.59
Fam. x Ant/Post	1,27	4.41	274.8	.045*
Fam. x Electrode	4,108	1.32	32.6	.27
Fam. x Hemi x Ant/Post	1,27	0.008	0.12	.93
Separate for Anterior and Posterior electrodes				
Anterior	1,27	6.30	1696.1	.018*
Posterior	1,27	2.29	314.7	.14

Note. Fam. =Familiarity; Hemi = Hemisphere; Ant/Post = Anterior/Posterior
*p<.05 **p<.01 ***<.001

Supporting Table 5

ANOVA on mean ERP amplitude in the 600 to 900 ms latency range time-locked to familiarized versus unfamiliarized target words in the test phase.

source	df	F	MSE	p
ANOVA: Familiarity (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Familiarity	1,27	6.25	2246.8	.019*
Fam. x Hemi	1,27	0.001	0.10	.97
Fam. x Ant/Post	1,27	7.67	675.8	.010*
Fam. x Electrode	4,108	1.43	100.5	.24
Fam. x Hemi x Ant/Post	1,27	0.15	4.40	.70
Separate for Anterior and Posterior electrodes				
Anterior	1,27	10.73	5092.2	.003**
Posterior	1,27	6.92	1358.3	.014*

Note. Fam. =Familiarity; Hemi = Hemisphere; Ant/Post = Anterior/Posterior
*p<.05 **p<.01 ***<.001

APPENDIX 3D: SUPPORTING TABLES OF CHAPTER 5

Supporting Table 1

ANOVA on mean ERP amplitude in the 350 to 450 ms latency range time-locked to familiarized versus unfamiliarized target words in the test phase, for only those infants who participated in follow-up tests.

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,22	0.86	242.0	.36
Fam. x Qua.	3,66	5.17	129.7	.005**
Separate per Quadrant				
Left frontal	1,22	0.48	49.5	.50
Right frontal	1,22	4.36	355.3	.049*
Left posterior	1,22	0.42	39.3	.53
Right posterior	1,22	1.95	132.1	.18

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 2

ANOVA on mean ERP amplitude in the 200 to 500 ms latency range time-locked to the first two tokens versus last two tokens of target words in the familiarization phase, for only those infants who participated in follow-up tests, and with Group as between-subjects factor (P-responders, N-responders).

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5) x Group (2)				
Familiarity	1,21	5.13	1526.6	.034*
Fam. x Group.	1,21	0.001	0.34	.97
Fam. x Qua.	3,63	3.11	66.9	.032*
Fam. x Qua. x Group	3,63	1,64	35.2	.19

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

APPENDIX 3E: SUPPORTING TABLES OF CHAPTER 6

Supporting Table 1

ANOVA on mean ERP amplitude in the 200 to 500 ms latency range time-locked to the first two tokens versus last two tokens of target words in the familiarization phase, for only those infants who participated in follow-up tests, and with Group as between-subjects factor (P-responders, N-responders).

source	df	F	MSE	p
ANOVA: Familiarity (2) x Quadrant (4) x Electrode (5)				
Familiarity	1,21	6.72	7957.0	.017*
Fam. x Group	1,21	0.23	271.7	.64
Fam. x Qua.	3,63	4.15	1265.4	.013*
Fam. x Qua. x Group	3,63	0.74	226.2	.51

Note. Fam. =Familiarity; Qua = Quadrant. *p<.05 **p<.01 ***<.001

Supporting Table 2

Pair-wise Comparisons on mean ERP amplitude over 20 lateral electrodes in the 200 to 500 ms latency range time-locked to the first two tokens (1&2) compared to the third and fourth or the fifth and sixth or the seventh and eighth or the ninth and tenth tokens of target words in the familiarization phase, for Negative and Positive responders, split by whether the subjects comprised only those infants who participated in follow-up tests, or the complete original sample, respectively.

Supporting Table 2a: for Negative Responders

Pairing	Comparisons	Mean Difference	95% C.I. for difference	T	p
Only for infants who returned at follow-up				**T (13)**	
1&2	3&4	7.10	+1.01 - +13.2	2.52	.026*
	5&6	10.0	+5.49 - +14.55	4.78	<.001***
	7&8	9.53	+0.15 - +18.9	2.20	.047*
	9&10	13.5	+4.70 – + 22.3	3.31	.006**
For all infants				**T (17)**	
1&2	3&4	6.29	+1.17 - +11.4	2.52	.019*
	5&6	8.61	+4.89 - +12.35	4.88	<.001***
	7&8	8.57	+0.15 - +18.9	2.48	.024*
	9&10	12.5	+5.63 - +19.4	3.83	.001**

Note. *p<.05 **p<.01 ***p<.001

Supporting Table 2b: for Positive Responders

Pairing	Comparisons	Mean Difference	95% C.I. for difference	T	p
Only for infants who returned at follow-up				**T (8)**	
1&2	3&4	2.39	-3.76 - +8.50	0.89	.40
	5&6	2.76	-6.15 - +11.7	0.72	.50
	7&8	0.85	-5.05 - +6.76	0.33	.75
	9&10	8.44	+0.29 - +16.6	2.39	.044*
For all infants				**T (9)**	
1&2	3&4	2.73	-2.71 - +8.18	1.14	.29
	5&6	2.79	-5.03 - +10.6	0.81	.44
	7&8	2.36	-3.84 - +8.57	0.86	.41
	9&10	8.13	+0.94 - +5.3	2.56	.031*

Note. *p<.05 **p<.01 ***p<.001

Supporting Table 3

ANOVAs on mean ERP amplitude in the 350-450 ms latency range time-locked to familiarized and unfamiliar words in the test phase, for all infants who returned and with Vocabulary Group (LV, HV) as between-subjects factor (Supporting Table 3a); for infants with Lower Vocabularies (Supporting Table 3b) and for infants with Higher Vocabularies (Supporting Table 3c), respectively.

Supporting Table 3a

For all infants who returned at follow-up

source	df	F	MSE	p
ANOVA: Familiarity (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5) x Group (2)				
Familiarity	1,21	1.56	890.3	.23
Fam. x Group	1,21	0.22	127.2	.64
Fam. x Hemi	1,21	1.73	185.8	.20
Fam. x Hemi x Group	1,21	0.074	7.90	.79
Left hemisphere				
Fam.	1,21	2.95	944.7	.10
Fam. x Group	1,21	0.31	99.2	.58

Note. Fam. =Familiarity; Hemi = Hemisphere. *p<.05 **p<.01 ***<.001

Supporting Table 4a

For infants with Lower Vocabularies

source	df	F	MSE	p
ANOVA: Familiarity (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Familiarity	1,10	1.08	810.1	.32
Fam. x Hemi	1,10	0.92	129.5	.36
Separate for Left hemisphere				
Left hemisphere	1,10	2.79	793.7	.13

Note. Fam. =Familiarity; Hemi = Hemisphere. *p<.05 **p<.01 ***<.001

Supporting Table 4b
For infants with Higher Vocabularies

source	df	F	MSE	p
ANOVA: Familiarity (2) x Hemisphere (2) x Anterior/Posterior (2) x Electrode (5)				
Familiarity	1,11	0.44	180.1	.52
Fam. x Hemi	1,11	0.79	61.2	.39
Separate for Left hemisphere				
Left hemisphere	1,11	0.64	225.6	.44

Note. Fam. =Familiarity; Hemi = Hemisphere. *p<.05 **p<.01 ***<.001

SAMENVATTING

Baby's beginnen met praten rond hun eerste verjaardag. Dit is verrassend snel, als je bedenkt dat de gemiddelde baby dan nog niet eens kan lopen, laat staan zijn veters kan strikken! Al ruim voor ze een jaar oud zijn, zijn er tekenen dat een baby is begonnen met het leren van één taal in het bijzonder: de moedertaal. Zo luistert een baby bij de geboorte al langer naar zijn moedertaal dan naar een taal met een andere ritmische structuur. Rond vier maanden kan de baby een onderscheid maken tussen zijn moedertaal en een andere taal met dezelfde ritmische structuur, bijvoorbeeld tussen het Nederlands en het Engels. Inmiddels reageert de baby ook al op zijn eigen naam. En hoewel het leren van de betekenis van woorden pas vanaf 12 maanden na de geboorte een grote vlucht neemt, blijkt uit experimenteel onderzoek dat baby's al vanaf zes maanden beginnen met het begrijpen van de allereerste woordjes, zoals 'papa', 'mama', 'schoen' en 'sok'. Het leren van de eerste woordjes is een tijdrovend proces: Rond negen maanden begrijpt een gemiddelde baby rond de 15 woorden ('receptieve of passieve woordenschat'), en zegt zelf meestal nog geen woord, hooguit één à twee woorden ('actieve woordenschat'). Met twaalf maanden bestaat de passieve woordenschat al uit 50 – 75 woorden. Het is duidelijk dat in deze periode de meeste woorden eerder begrepen worden dan dat ze uitgesproken worden.

Het leren begrijpen van woorden vereist niet alleen dat een baby de koppeling tussen een woordvorm en het concept - daar waarnaar een woord verwijst - kan maken, maar ook dat de baby zowel de woordvorm als het concept zelf als zodanig herkent, in verschillende contexten en situaties. Al deze vaardigheden zijn minder makkelijk dan ze op het eerste gezicht lijken.

Kijkt u bijvoorbeeld eens naar Figuur 1.1 op pagina 19, waar een situatie wordt geschetst voor het leren van het word 'flesje'. Het *concept* 'flesje' te kunnen herkennen vereist niet alleen dat het meisje haar eigen flesje herkent in verschillende situaties (leeg of gevuld met water, melk of thee bijvoorbeeld) maar ook moet ze leren dat andere flesjes ook tot dezelfde categorie horen.

Daarnaast moet het meisje het *woord* 'flesje' herkennen. Omdat uit onderzoek is gebleken dat ouders vooral in zinnetjes tegen hun kind spreken, betekent dit dat het meisje het woord 'flesje' moet herkennen tussen de andere woorden. Ook dit is lastiger dan u misschien zult denken. Als volwassen spreker van uw moedertaal bent u zo ervaren met het luisteren naar woorden in het Nederlands dat u zonder moeite de woorden van elkaar kunt onderscheiden. Echter, als u een vreemde taal nog niet goed beheerst, dan lijkt het alsof mensen in die taal altijd te snel praten. Denk maar aan de luistertoetsen Frans op de middelbare school: Het begrijpen van gesproken Frans is een stuk moeilijker dan het lezen van een Franse tekst. Dit komt deels omdat in geschreven taal alle woorden door spaties van elkaar gescheiden zijn, terwijl in gesproken taal de woorden 'aan elkaar geplakt' zijn en elkaar zelfs overlappen. Dit is bijvoorbeeld te zien in de visuele weergave van het akoestische signaal 'waar is je flesje nou' in Figuur 1.1. Bij het leren van een vreemde taal moet men dus leren een zin op zo'n manier 'in stukjes te hakken' dat duidelijk is waar een woord eindigt en een ander woord begint. Dit moeten baby's voor hun moedertaal ook leren. Voordat ze zelf beginnen te praten moeten ze immers weten hoe een typisch Nederlands woord begint en eindigt. Kenmerkend voor een Nederlands woord van twee lettergrepen is dat de eerste lettergreep meestal beklemtoond is: FLES-je, MA-ma en LUI-er, bijvoorbeeld. Deze kennis kunnen ze gebruiken om een zin goed in stukjes te hakken (segmenteren) zodat ze vervolgens kunnen beginnen met het herkennen van woorden onafhankelijk van de andere woorden die eromheen staan.

In dit proefschrift neem ik het passief leren van de eerste woordjes - voor de eerste verjaardag - onder de loep. Vergeleken met het reeds bestaande onderzoek naar de ontwikkeling en verloop van de actieve woordenschat is juist de periode voorafgaand aan dit stadium nog behoorlijk onderbelicht. Dit is niet zo vreemd: Het is namelijk veel makkelijker om waar te nemen welke woorden kinderen al actief gebruiken dan welke ze als eerste gaan begrijpen of herkennen. Het passsief leren van woorden bij baby's heb ik in drie experimenten onderzocht. Daarnaast heb ik in alle experimentele hoofdstukken onderzocht of de verschillen in receptieve woordherkenning tussen baby's samenhangen met hun latere taalontwikkeling. De taalontwikkeling van kinderen is immers zeer variabel: Sommige kinderen zeggen hun eerste woordjes al vanaf een leeftijd van acht maanden, maar anderen pas rond de vijftien maanden. Een klein aantal kinderen zegt zelfs met twee jaar nog geen woord. Als de verschillen in taalontwikkeling op latere leeftijd inderdaad te herleiden zijn naar verschillen in woordherkenning op vroegere leeftijd, dan geeft dit niet alleen aan hoe belangrijk de fase van het passief leren van woorden is, maar biedt dit ook mogelijkheden om taalstoornissen bij kinderen te herkennen of om nieuwe therapieën te ontwikkelen.

Om te onderzoeken of baby's passief woorden kunnen herkennen heb ik voornamelijk gebruik gemaakt van een methode waarbij het niet nodig is dat ze ook echt waarneembaar reageren op de woorden. Dit heb ik gedaan door baby's vertrouwd te maken met bepaalde woorden terwijl tegelijkertijd hun (elektrische) hersenactiviteit werd geregistreerd door middel van een elektro-encefalogram (EEG). Hierbij wordt gebruik gemaakt van een soort badmuts met sensoren, die de kleine elektrische golfjes kunnen meten die door de baby worden geproduceerd tijdens bijvoorbeeld het luisteren naar taal (zie Figuur 1.2 op pagina 26). Op basis van dit EEG kan worden vastgesteld welke elektrische activiteit samenhangt met het aanbieden van een bepaalde 'gebeurtenis' zoals het horen van een herhaald dan wel nieuw woord. Deze gebeurtenis-gerelateerde hersenpotentialen (event-related potentials) worden ERPs genoemd. Vervolgens wordt gekeken of de ERPs voor herhaalde en nieuwe woorden van elkaar verschillen. Als dit het geval is, dan kan men hieruit concluderen dat het babybrein de herhaling heeft opgemerkt.

In het eerste experimentele hoofdstuk (Hoofdstuk 2) heb ik de hersenpotentialen onderzocht van de drie vaardigheden die nodig zijn voor het leren van woorden: (visuele) conceptherkenning, woordherkenning en het koppelen van woord aan concept. Om dit te onderzoeken kwamen baby's van negen maanden oud met hun ouders naar het Baby Research Center en kregen ze een EEG-badmuts op om zo hun hersensignalen te meten. Hierbij heb ik eerst gekeken naar wat er in het babybrein gebeurt als de baby herhaaldelijk afbeeldingen van een bepaalde categorie op een computerscherm zag en daarbij het betreffende woord hoorde. Tevens onderzocht ik of het voor het herkennen van nieuwe exemplaren van dezelfde soort nog uit maakt of baby's in de oefenfase maar één specifiek exemplaar vaker gezien hadden, of verschillende exemplaren maar één keer? In de oefenfase hebben ze bijvoorbeeld voor het woord 'poes' dan wel zes verschillende poezen, dan wel zes keer dezelfde poes te zien gekregen. Bij elke afbeelding hoorden ze dan ook het woord 'poes'. Na een oefenfase van 'poes' kregen ze dan zes keer een oefenfase van het woord 'bal' te zien die ook weer uit allemaal verschillende ballen bestond, of uit zes keer dezelfde bal.

Uit de resultaten wat betreft het herkennen van concepten blijkt dat het verwerken van een afbeelding inderdaad afhangt van de hoeveelheid verschillende afbeeldingen van hetzelfde concept: De kenmerkende hersenpotentiaal voor het verwerken van een afbeelding is een grote negatieve golf ('Negative-central component') die groter is voor *verschillende* afbeeldingen dan wanneer de afbeelding steeds de zelfde blijft. Daarnaast is de amplitude van deze component afhankelijk van herhaling: hoe vaker een bepaald concept wordt herhaald, hoe kleiner de negatieve golf.

Vervolgens heb ik gekeken naar woordherkenning: Elke keer dat er een afbeelding verscheen op het beeldscherm in de oefenfase werd een seconde later het passende woord erbij afgespeeld. De gemiddelde hersenpotentiaal voor woordverwerking bij baby's rond 9 maanden kenmerkt zich door een grote positieve golf. Uit deze resultaten blijkt dat deze golf beïnvloed wordt door herhaling: De amplitude van de golf neemt af naarmate een woord vaker herhaald wordt tijdens de oefenfase. Het maakt voor het woordherkenningseffect ('word familiarity effect') qua timing en amplitude verder niet uit of de afbeeldingen nu constant blijven of dat ze verschillend zijn.

Om te testen of dezelfde baby's ook betekenis konden koppelen aan onbekende poezen en ballen, kregen ze na de oefenfase nieuwe plaatjes van ballen en poezen te zien op het scherm, die soms de goede naam kregen (woord poes - afbeelding van poes) en soms de naam van de andere categorie (woord poes – afbeelding van bal). Zo heb ik de vaardigheid van het koppelen van woord aan concept onderzocht. Als de hersenpotentiaal voor een woord dat niet klopt bij de afbeelding anders is dan de hersenpotentiaal voor een woord dat wel strookt met de afbeelding dan toont dit aan dat de baby's het gehoorde woord inderdaad betrekken op de afbeelding die ze tegelijkertijd te zien krijgen en dat ze dus een koppeling maken tussen woord en beeld. Onderzoek bij volwassenen wijst uit dat de hersenen een 'N400'-effect laten zien - vooral achterop het hoofd - als het woord niet klopt met het beeld, ten opzichte van wanneer het woord wel zou passen bij een afbeelding. De 'N400' is een zeer bekend effect in de psycholinguïstiek, en wordt soms ook wel het 'huh-effect' genoemd. Het treedt gemiddeld 400 ms nadat een woord gepresenteerd is op, en is negatiever als een woord qua betekenis niet past in de context. Uit eerder Duits onderzoek was gebleken dat 12-maanden-oude baby's dit effect nog niet laten zien. Daardoor werd gedacht dat het N400-mechanisme bij een leeftijd van 12 maanden nog niet rijp was. Uit het onderzoek in Hoofdstuk 2 blijkt echter dat 9-maanden-oude baby's al een N400-effect kunnen laten zien. Voor aanvang van de N400 is er bovendien nog een fonologisch effect waarneembaar rond 200 ms: de N200. Dit eerdere effect is waarschijnlijk het gevolg van het feit dat de beginklanken van het niet- kloppende woord ('ba' van 'bal'), altijd anders waren dan die van het (verwachte) kloppende woord ('poe' van 'poes'). Vermoedelijk heeft de oefenfase de koppeling tussen woord en concept zo versterkt dat de baby's bij het zien van nieuwe exemplaren al een verwachting hebben over welk woord ze dan zullen gaan horen. Het maakt hierbij niet uit of ze tijdens de oefenfase verschillende exemplaren hebben gezien of maar één exemplaar meerdere keren. De baby's hoeven dus niet eens het hele woord gehoord te hebben voordat hun brein weerspiegelt dat het gehoorde woord niet overeenkomt met de woordvorm dat ze verwachten. De N400 geeft vervolgens weer dat het gehoorde woord ook qua betekenis niet klopt.

Omdat een tweede doel van dit proefschrift is te onderzoeken hoe de individuele variatie voor woorden leren samenhangt met de woordenschat, hebben de ouders van de baby's na afloop een vragenlijst ingevuld waarop ze aangaven welke woorden hun kind al begreep of zei en welke nog niet. Hieruit blijkt dat er op een leeftijd van negen maanden een correlatie bestaat tussen het aantal woorden dat de baby's al begrepen en de maat van de N400: hoe groter de N400 achterop het hoofd, des te meer woorden ze begrijpen.

De resultaten van dit experiment geven meer inzicht in de neurale processen van visuele categorisatie, woordherkenning en de koppeling tussen woord en concept: de drie vaardigheden die cruciaal zijn voor het opbouwen van een woordenschat. Het woordherkenningseffect is hier echter gevonden terwijl baby's luisterden naar losse woorden. Zoals eerder gezegd weten we dat baby's vooral woorden horen in continue spraak. Om hierin woorden te herkennen moeten ze deze segmenteren uit de rest van de uiting. In hoofdstuk 3 en 4 ga ik in op de vraag of baby's woorden ook kunnen herkennen als ze midden in een zin voorkomen. Hier heb ik specifiek onderzocht hoe vaak ze een woord gehoord moeten hebben en in welke context - los dan wel omringd door andere woorden - voordat het woordherkenningseffect optreedt. In tegenstelling tot hoofdstuk 2 gaat het hier dus om het herkennen van woordvormen zonder dat er een betekenis aan gegeven wordt. Om een woordenschat op te bouwen moeten baby's hoe dan ook woordvormen kunnen herkennen en onthouden. Verder heb ik onderzocht hoe het woordherkenningseffect samenhangt met de latere taalontwikkeling; dit onderwerp komt zowel aan de orde in hoofdstuk 3 en 4, als ook in hoofdstuk 5 en 6.

Bij het onderzoek dat centraal staat in Hoofdstuk 3 heb ik onderzocht of baby's van 10 maanden een los woord kunnen herkennen dat ze net daarvoor slechts één keer eerder gehoord hebben. De eerste keer dat ze het woord hoorden werd het òf midden in een zin aangeboden, òf als een los woord. Ze hoorden bijvoorbeeld eerst een zin 'de oude hommel zit op het gordijn', gevolgd door het losse woord 'hommel' dan wel 'mammoet'. Als er nu een woordherkenningseffect optreedt voor het herhaalde woord 'hommel' in vergelijking met het niet-herhaalde woord 'mammoet', dan kunnen de baby's niet alleen de beginzin goed in stukjes hakken, maar ook nog eens de losse stukjes meteen onthouden. Uit de resultaten blijkt dat de baby's wel een woordherkenningseffect laten zien als ze het woord de eerste keer ook los hebben gehoord, maar niet als ze het binnen een zin hebben gehoord. Het is blijkbaar nog te moeilijk voor ze om meteen een zin te segmenteren en de onderdelen daarvan te onthouden. Echter, ongeveer de helft van de kinderen laat wel een woordherkenningseffect zien voor deze moeilijkere situatie. Omdat uit eerder onderzoek is gebleken dat het herkennen van woorden in continue spraak belangrijk is voor latere taalontwikkeling, werd daarom aan de ouders van de kinderen gevraagd om een zelfde soort woordenlijst als in Hoofdstuk 2 in te vullen toen hun kind 12 maanden was, en nog eens op tweejarige leeftijd. Daaruit blijkt dat de kinderen die relatief meer woorden begrijpen met 12 maanden juist degenen zijn die met 10 maanden in hun hersengolfjes een groter effect laten zien van woordherkenning, terwijl kinderen die relatief minder woorden begrijpen dit effect niet laten zien. Ook met 24 maanden bleef dit patroon bestaan. Het lijkt er dus op dat het voor baby's van 10 maanden erg moeilijk is om woorden te herkennen die ze slechts één keer eerder gehoord hebben midden in een zin: nog niet alle baby's kunnen dit. De baby's die dit al wel konden bleken op latere leeftijd een grotere woordenschat te hebben. Hieruit wordt aangetoond dat het vermogen om woorden te segmenteren uit continue spraak erg belangrijk is omdat het gerelateerd is aan de latere taalontwikkeling, in ieder geval tot de leeftijd van twee jaar.

Omdat uit het hiervoor genoemde onderzoek is gebleken dat sommige baby's meer moeite hadden met het herkennen van een enkel woord dat ze eerder éénmaal in een zin gehoord hebben en ook bekend is dat baby's normaliter continue spraak horen, heb ik in Hoofdstuk 4 onderzocht of baby's woorden kunnen herkennen *binnen* een zin. Deze woorden hebben ze dan al meerdere keren gehoord, steeds weer omringd door andere woorden. Opnieuw wordt hier dus onderzocht of de hersensignalen van baby's van 10 maanden verschillen voor een woord dat herhaald wordt, of een woord dat juist maar éénmaal wordt genoemd.

Eerst hoorden de baby's acht zinnetjes, waarbij een relatief onbekend woord steeds in het midden van de zin voorkwam, zoals "Die leuke drummer houdt van slagroom", en "hij was drummer van een band". Daarna hoorden ze vier nieuwe zinnen, waarbij de helft weer het woord 'drummer' bevatte, en de andere twee een nieuw woord, zoals 'hommel'. Ook hier is het woordherkenningseffect weer zichtbaar: de ERP voor herhaalde woorden is negatiever van polariteit dan dat van de nieuwe woorden. Baby's van 10 maanden kunnen dus al woorden herkennen in continue spraak als ze die daarvoor meerdere keren in zinnetjes gehoord hebben.

In Hoofdstuk 4 is verder de samenhang tussen de grootte van het woordherkenningseffect en latere taalontwikkeling onderzocht. In plaats van de eerder gebruikte woordenlijsten kwamen nu de baby's met 16 maanden terug naar het Baby Research Center om mee te doen aan een eye-tracking test. Hierbij kregen ze steeds twee plaatjes naast elkaar te zien, terwijl er met behulp van een geluidsfragment naar één onderwerp werd gevraagd. Zo zagen ze bijvoorbeeld een auto en een bal, en hoorden ze ' Waar is de bal?'. Bij eye-tracking registreren kleine cameraatjes vervolgens hoe lang de kinderen naar het goede voorwerp blijven kijken op het moment dat ze dat woord horen. Omdat dit iets zegt over de mate van herkenning van een woord kan met deze test het woordbegrip van kinderen objectief gemeten worden zonder dat dit aan de ouders gevraagd moet worden. Doorgaans geldt dat hoe langer baby's naar het goede object kijken, des te beter ze de relatie tussen woord en object hebben opgeslagen. Uit de resultaten van deze test blijkt dat kinderen die met 16 maanden relatief lang naar het goede voorwerp bleven kijken een groter effect van woordherkenning hadden laten zien met 10 maanden dan kinderen die maar kort naar het goede voorwerp keken. Het vermogen van de kinderen om woorden te herkennen middenin zinnen, op een leeftijd van 10 maanden, is dus gerelateerd aan hoe ze zich een half jaar later hebben ontwikkeld op het gebied van taal.

De experimenten beschreven in hoofdstuk 3 en 4 waren niet de eerste ERP-onderzoeken naar het vermogen van baby's om woorden te herkennen in continue spraak. Valesca Kooijman (2007) heeft hier eerder onderzoek naar gedaan en vergeleek hierbij baby's van 10 maanden oud met baby's van zeven maanden oud. Het experiment was voor beide groepen gelijk: baby's hoorden eerst 10 keer hetzelfde losse woord voordat gekeken werd of ze het woord konden herkennen binnen een zin. Bij beide groepen vond ze een woordherkenningseffect, dat echter verschilt in polariteit. Net als bij de baby's die deelnamen aan de onderzoeken in Hoofdstuk 2, 3, en 4 - leeftijd negen tot 10 maanden -, was het verschil tussen het ERP van herhaalde versus nieuwe woorden voor baby's van 10 maanden negatief van polariteit. Bij baby's van zeven maanden was dit precies omgekeerd. Op die leeftijd bleek de hersenpotentiaal van herhaalde woorden positiever dan dat van nieuwe woorden. Bij beide leeftijden is er echter ook een klein aantal kinderen dat een woordherkenningseffect laat zien dat lijkt op dat van de andere leeftijdsgroep. In Hoofdstuk 5 en 6 staat dan ook de vraag centraal of de onderlinge verschillen tussen kinderen wat betreft het woordherkenningseffect dat ze als baby laten zien, nog steeds zichtbaar zijn als gekeken wordt naar hun latere taalontwikkeling. De baby's van het eerdere onderzoek zijn dan inmiddels al peuters en kleuters geworden.

In het onderzoek van Hoofdstuk 5 zijn de baby's die met zeven maanden waren getest - inmiddels drie jaar oud -, getest op hun taalvaardigheden door middel van gestandaardiseerde taaltoetsen. Hierbij heb ik niet alleen zinsbegrip getest, maar ook de actieve woordenschat en het vermogen om ingewikkelde zinnen te maken. Ook hebben de ouders een vragenlijst gekregen waarin zij bepaalde aspecten van de taalontwikkeling van hun kind moesten vergelijken met dat van andere kinderen van dezelfde leeftijd. Vervolgens heb ik onderzocht of er een verband bestaat tussen de vroegere hersenpotentialen voor woordherkenning en de resultaten van de taaltoetsen. Hierbij verdeelde ik de baby's van zeven maanden in twee groepen: de P-responders: kinderen die een woordherkenningseffect lieten zien met een positieve polariteit welke passend is voor deze leeftijdsgroep, en de N-responders: kinderen die een woordherkenningseffect lieten zien met een negatieve polariteit welke passend is voor baby's van 10 maanden. Het blijkt dat de kinderen die met zeven maanden al een effect lieten zien dat kenmerkend is voor oudere baby's (de N-responders) op alle toetsen hoger scoren dan de P-responders. Hetzelfde patroon is ook zichtbaar in de beoordelingen van de ouders: N-responders worden hoger ingeschat dan de P-responders. Hieruit blijkt nogmaals dat het vermogen om zinnen in stukjes kunnen te hakken zodat woorden herkend kunnen worden, erg belangrijk is voor de latere taalontwikkeling, in ieder geval tot drie jaar.

In Hoofdstuk 6 kwamen juist de baby's terug die oorspronkelijk met 10 maanden waren getest. Zij waren inmiddels ruim vijf jaar, en gingen allemaal al naar de kleuterschool. Zien we hier weer een relatie tussen de babyhersenpotentialen voor woordherkenning in gesproken taal en de latere taalontwikkeling, zelfs als de kinderen vijf jaar zijn? Om dit te onderzoeken heb ik hun latere taalvaardigheden op dezelfde manier getest als bij de kinderen in Hoofdstuk 5. Weer worden de kinderen verdeeld in twee groepen: de grootste groep bestond nu uit de N-responders die een negatief woordherkenningseffect lieten zien, en de andere groep uit de P-responders die dus een effect lieten zien dat kenmerkend was voor een jongere leeftijdsgroep. Behalve het feit dat beide groepen verschillen van elkaar wat betreft de polariteit van het woordherkenningseffect voor herhaalde woorden in zinnen, is er tijdens dit onderzoek nog een verschil tussen de groepen gevonden in de babydata, namelijk na hoeveel herhalingen ze een woord herkenden, in de fase waarin ze vertrouwd werden gemaakt met het woord dat in deze fase 10 keer los werd aangeboden. Hoewel beide groepen een soortgelijk verschil laten zien voor het begin versus het einde van deze fase, blijkt dat de N-responders hier minder vaak het woord hoeven te horen voordat ze een woordherkenningseffect laten zien dan bij de P-responders het geval is. Daarentegen verschillen de groepen niet meer van elkaar wat betreft de taalontwikkeling op vijfjarige leeftijd. Het vermogen om woorden te herkennen in gesproken taal valt dus wel samen met een andere taalvaardigheid met 10 maanden maar is niet meer bepalend voor de taalvaardigheden van kinderen van vijf jaar. Waarschijnlijk zijn er hier andere factoren van belang die de variatie tussen deze kinderen zouden kunnen verklaren, maar die nog geen rol speelden bij de vroege taalontwikkeling, zoals bijvoorbeeld het feit dat ze begonnen zijn met naar school gaan.

Hoofdstuk 7 geeft een samenvatting en discussie van de resultaten en tevens suggesties voor verdere onderzoeken. Eerst wordt het woordherkenningseffect vergeleken met soortgelijke effecten die zijn gevonden in andere studies. Uit dit overzicht blijkt onder andere dat kleine verschillen in de timing of distributie van het woordherkenningseffect waarschijnlijk samenhangen met de moeilijkheidsgraad van de situaties waarin baby's worden getoetst op hun vaardigheid om te herkennen. Juist hier toont het ERP onderzoek zijn waarde. We zien niet alleen òf maar ook *wanneer* baby's een woord herkennen. Daarnaast laat dit overzicht zien dat het woordherkenningseffect niet alleen optreedt bij het herkennen van woordvormen - waarbij de betekenis nog geen rol speelt - maar ook bij het herkennen van woorden die de baby wel of niet begrijpt, zoals 'poes' versus 'munt'. Verder wordt de conclusie getrokken dat het vermogen van baby's om zinnen zodanig in stukjes te hakken dat woorden herkend kunnen worden een erg belangrijke vaardigheid is voor het bouwen van de woordenschat, zoals aangetoond is in de hoofdstukken 3, 4 en 5. Baby's die een woordherkenningseffect laten zien in een onderzoek waarbij het nodig was om het continue spraaksignaal op te breken in losse woorden, zijn op latere leeftijd bekwamer in hun taalvaardigheden, in ieder geval tot ze drie jaar oud zijn.

CURRICULUM VITAE

Caroline Junge (Niedorp, 1981) studied English Literature and Linguistics (with a minor in Psycholinguistics) as well as Cognitive Science at the University of Amsterdam. In 2007 she received her doctoral degree in English Literature and Linguistics, and her MSc degree in Cognitive Science (cum laude). In the same year, she was awarded a three-year scholarship from the Max Planck Society to carry out her PhD research at the Max Planck Institute for Psycholinguistics in Nijmegen, the Netherlands. Here, she joined the newly founded Neurobiology of Language Group as well as the Language Comprehension Group. This thesis is the result of her work during that period. In 2010, she was awarded a visiting researchers grant from the ESRC Centre for Research on Bilingualism in Theory and Practice, which allowed her to spend four months as a visiting scholar at Bangor University in Wales to collaborate with Dr. Mills. Caroline currently works as a postdoctoral researcher at the babylab in Leiden University, where she joined the Leiden University Centre for Linguistics.

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Frank Seifart

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Anne Pier Salverda

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Mirjam Broersma

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Oliver Müller

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Frank Eisner

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Keren B. Shatzman

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Rebecca Özdemir

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Mandana Seyfeddinipur

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    Susanne Brouwer

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    Stuart Robinson

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    Sonja Gipper

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    Lin Wang

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