

Productive Vocabulary Size Predicts Event-related Potential Correlates of Fast Mapping in 20-Month-Olds

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Abstract

■ Although it is well documented that children undergo a productive vocabulary spurt late in the second year, it is unclear whether this development is accompanied by equally significant advances in receptive word processing. In the present study, we tested an electrophysiological procedure for assessing receptive word learning in young children, and the impact of productive vocabulary size for performance in this task. We found that 20-month-olds with high productive vocabularies displayed an N400 incongruity effect to violations of

trained associations between novel words and pictures, whereas 20-month-olds with low productive vocabularies did not. However, both high and low producers showed an N400 effect for common real words paired with an incongruous object. These findings indicate that there may be substantial differences in receptive fast mapping efficiency between typically developing children who have reached a productive vocabulary spurt and typically developing children who have not yet reached this productive spurt. ■

INTRODUCTION

When beginning to produce words around their first birthday, most children do so only slowly and laboriously, adding perhaps one or two words a week to their productive vocabulary. However, at some point late in the second year, the word acquisition rate typically starts to increase dramatically, with many children producing more than five new words a day (Fenson et al., 1994; Benedict, 1979). This steep increase in productive vocabulary size has received considerable attention in the linguistic and psychological literature and is often referred to as the vocabulary spurt (Goldfield & Reznick, 1990). Although some studies have questioned the existence of a spurt and claimed that a gradual increase model better describes the typical vocabulary development (e.g., Ganger & Brent, 2004), most researchers agree that the productive language development taking place in the second half of the second year is a developmental milestone (Bates, Thal, Finlay, & Clancy, 2002).

Fast mapping, that is, the ability to form an initial association between a word and its referent in just a few exposures, has been assumed to be an important contributor to the vocabulary spurt (Golinkoff, Hirsh-Pasek,

Bailey, & Wenger, 1992; Markman, 1989). As fast mapping has been regarded as a general ability which is vital for learning of new words in both comprehension and production (Markman, 1991), it has been expected that fast mapping in both the receptive and productive domain emerges around the time of the vocabulary spurt. However, a number of recent experimental studies have shown that infants are already capable of receptive fast mapping at the beginning of the second year, several months before productive language development starts to accelerate (Schafer & Plunkett, 1998; Werker, Cohen, Lloyd, Casasola, & Stager, 1998; Woodward, Markman, & Fitzsimmons, 1994). These findings have been used to argue against theories which posit that the vocabulary spurt results from general changes in word learning competence affecting both comprehension and production, and in favor of explanations in terms of production-specific abilities such as improved articulatory control or gains in motivation to communicate (Ninio, 1995; Woodward et al., 1994). However, it does not follow from the fact that 13- to 15-month-olds are able to learn word-object associations in relatively few co-presentations that there may not be further, and vital, developments in fast mapping ability around the time of the productive vocabulary spurt. Consequently, it is possible that such subsequent advances in fast mapping, or in general linguistic abilities affecting both receptive fast mapping and productive language, are important contributors to the vocabulary

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spurt. If this is the case, one should expect a robust relation between fast mapping skills and vocabulary size around the time of the vocabulary spurt.

Very few studies have addressed the relation between productive vocabulary size and fast mapping in children below the age of 2 years, and these have yielded conflicting results. In a study by Woodward et al. (1994), 13- and 18-month-olds with more than 50 words in their vocabulary demonstrated fast mapping skills, whereas children with less than 50 words in their vocabulary did not. In line with this, Mervis and Bertrand (1994) found that 16- to 20-month-olds, who demonstrated ability to fast map, had significantly higher productive and receptive vocabularies than children who did not demonstrate fast mapping. On the other hand, Tan and Schafer (2005), who also tested 16- to 20-month-olds, found no relation between vocabulary size and the ability to learn the association between novel words and their referents. It should be noted, however, that the two former studies differed from the latter in the choice of experimental paradigm. Although the experiments by Woodward et al. and Mervis and Bertrand were carried out in close communication between the experimenter and the child, Tan and Schafer used the preferential looking paradigm, in which no social cues or interaction with an experimenter were involved. The differential results may therefore be due to effects of vocabulary size on the ability to cooperate with an experimenter. However, it may also be that the fast mapping task employed by Tan and Schafer, which included only two novel words, was too simple to tease apart children of different vocabulary sizes. Consequently, it is an open question whether effects of productive language on fast mapping abilities can be seen in a task which does not involve additional demands such as interaction with an experimenter.

The purpose of the present study was twofold. First, we aimed to test an electrophysiological procedure for assessing receptive word learning in children. Second, we sought to investigate whether typically developing children of the same chronological age (20 months), but of different productive vocabulary sizes, would perform differently in such a receptive task. This investigation represented a first step to illuminate the relation between receptive word learning and the productive vocabulary spurt, which could potentially serve as a starting point for further experiments. The idea behind the experimental design was to build up associations between specific novel words and pictures through repeated co-presentations, and then violate these associations by presenting the words together with different, but equally familiar, pictures. As opposed to earlier studies of fast mapping, which have tended to use only one or a couple of new labels, the current study included 30 novel words to be learnt by the children.

As the object of study in the current experiment was the brain response to semantic incongruities, the N400 component was of particular interest. This event-related

potential (ERP) component is a well-studied index of semantic processing in adults (for a review, see Kutas & Federmeier, 2000), and was first demonstrated in young children (19-month-olds) by Friedrich and Friederici (2004), in response to words which did not match the content of a picture. Later studies have replicated this effect with different experimental designs (Torkildsen, Syversen, Simonsen, Moen, & Lindgren, 2007b; Torkildsen et al., 2006), and shown evidence that it is present in children as young as 13 to 14 months of age (Friedrich & Friederici, 2005a; Mills, Conboy, & Paton, 2005), but not in 12-month-olds (Friedrich & Friederici, 2005b). The results of these earlier studies lead us to predict that we will see an N400 incongruity effect for violations of the trained word–picture associations in the present study. Such an incongruity response would be evidence of fast mapping. Differences between children with high and low vocabularies in the predicted incongruity response could thus indicate an effect of productive vocabulary on fast mapping abilities.

Although there is an increasing amount of ERP studies on word processing in toddlers, only one previous experiment with young children has investigated the effects of associating novel words with referents (Mills, Plunkett, Prat, & Schafer, 2005). As in the present experiment, Mills, Plunkett, et al. (2005) compared brain responses of 20-month-olds with high and low vocabularies in a word learning task. Their experiment involved four novel and two familiar words and consisted of three phases: a before-training phase where children were presented with each word 30 times, a training phase where half of the words were presented with an object 10 times (paired condition) and half of the words were presented without an object 10 times (not-paired condition), and an after-training phase where each word again was repeated 30 times. When comparing the before-training phase with the after-training phase, ERPs to the familiar and novel not-paired words became more positive in the 200–500 msec time interval, whereas ERPs to novel-paired words became more negative. There were no significant differences between high and low producers in the processing of novel words. Note, however, that Mills, Plunkett, et al. did not explicitly test whether children had fast mapped between words and referents, possibly because they were primarily interested in effects of vocabulary size on topographical differences in ERP contrasts between familiar and recently learned words. Because their experiment measured only whether the ERP response differed between words which had and had not been paired with an object, it is possible that the greater negativity for novel-paired words compared to the other conditions was due to other factors than fast mapping, such as increased attention to those unknown words that had been presented together with a referent.

In sum, the present study tests a controlled electrophysiological procedure for measuring word learning in

children. Moreover, it expands earlier research on the relation between productive vocabulary and receptive word learning by employing a task where (1) no interaction with an experimenter or other behavioral demands are involved, (2) the word learning load is high, and (3) fast mapping success is tested explicitly.

METHODS

Participants

Seventy-eight 20-month-old children were recruited through advertisements in magazines, newspapers, public health centers, and kindergartens. Data from 34 children were excluded due to refusal to wear the Electrocap ($n = 11$), technical problems during the recording ($n = 2$), or too few artifact-free trials in one or more of the experimental conditions ($n = 21$).

The 44 children (23 girls) who entered the final analyses were full born (>35 weeks of gestation), had no known neurological deficits, no language impairment in the immediate family, and no reported hearing or sight problems. According to parental report, there had been no serious complications during pregnancy or birth. Participants underwent testing when they were 20 months \pm 24 days.

Language Assessment

Within 1 week of the electroencephalogram (EEG) recording, parents completed a Norwegian adaptation (Smith, unpublished) of the MacArthur–Bates Communicative Development Inventory (MCDI) (Fenson et al., 1993). As the MCDI for this age group does not contain any measures of word comprehension, we included a list of the 30 real words used in the experiment, and asked parents to rate these as comprehended or not comprehended by the child.

The mean productive vocabulary on the MCDI was 117.7 words ($SD = 99.6$). On average, children produced 15.1 ($SD = 10.16$) of the 30 real words used in the experiment, and comprehended 25.1 ($SD = 5.8$) of these words. In a univariate analysis of variance (ANOVA) with total productive vocabulary as the dependent variable and sex as a fixed factor, there was a nonsignificant trend that girls produced more words than boys [$F(1, 42) = 2.79, p = .10$].

As the 50- to 75-word point is considered pivotal in language development and is supposed to coincide with the productive vocabulary spurt (e.g., Bates et al., 2002; Bates, Bretherton, & Snyder, 1988), participants were divided post hoc into a high production group and a low production group, with 75 words as a cutoff criterion. This division resulted in a high production group consisting of 25 subjects (15 girls) and a low production group consisting of 19 subjects (8 girls). Children in the high production group had a mean total productive

vocabulary of 178.8 words (range 78–419, $SD = 91.6$), produced 23.0 ($SD = 4.8$), and comprehended 27.1 ($SD = 3.5$) of the 30 real words used in the experiment on average. Children in the low-vocabulary group had a mean total productive vocabulary of 37.3 words (range 1–74, $SD = 22.0$), produced 4.6 ($SD = 3.5$), and comprehended 22.5 ($SD = 7.2$) of the 30 real words used in the experiment on average.

Stimuli

Auditory stimuli were 30 real words and 30 phonotactically legal novel words. The real words were taken from the MCDI and were names for basic-level objects, which were assumed to be familiar to 20-month-old children. Real and novel words were matched on number of syllables (20 one-syllable words and 10 two-syllable words in each group) and length (mean duration of approximately 570 msec in both groups). Novel words were constructed with the intention that they should not be confusable with the real words used in the experiment or other words that participants were likely to know. Therefore, we ensured that novel words differed from words in the MCDI and from each other in at least two phonemic contrasts. Words were slowly spoken in a female voice, and digitized at 16 bits with a 44.1-kHz sampling rate.

Visual stimuli were 30 color drawings which depicted referents for the real words and 30 color drawings which depicted fantasy objects and creatures. The drawings of fantasy objects and creatures were chosen from the Clipart.com database. The objects were not modified from real objects, and were selected with the intention that they should be difficult to associate with any existing lexical category. In order to minimize the risk that the novel pictures should be mistaken for each other, we ensured that they differed from each other in as many features as possible, particularly in shape and color. Moreover, stimuli were presented in blocks consisting of three novel and three real picture–word pairs, so that children were only required to keep track of the items in the ongoing block to succeed in the experimental task.

Procedure

The purpose of the experiment was to teach children an association between a novel word and a picture through five co-presentations and then violate this association by presenting this novel word with another picture. Real words and pictures of real objects were included in the experiment as a control of whether the N400 incongruity response was present in participants.

Participants were presented with 10 training–test blocks. Each block used three novel words and three real words. In the training phase, each of the six words was associated with their respective picture five times (Figure 1). The real words were associated with a con-

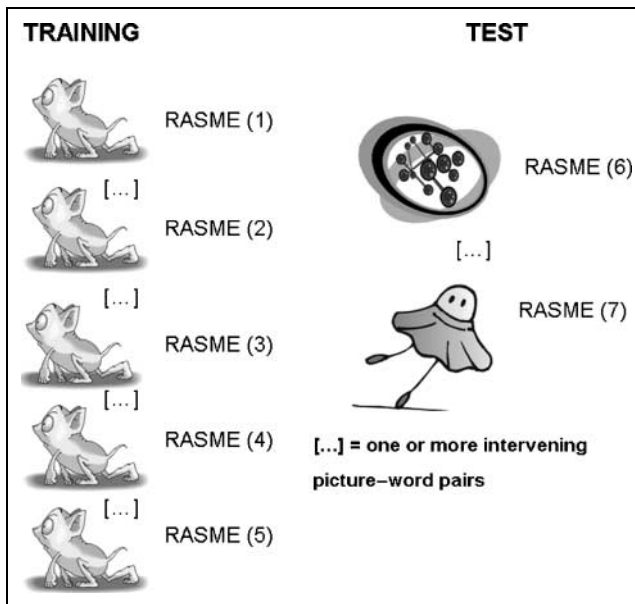


Figure 1. Outline of the experimental design. In the training phase, each word was paired with its respective picture five times. In the test phase, the words were presented together with two other, but equally familiar, pictures.

gruent basic level object (e.g., the word “dog” was associated with a picture of a dog), whereas the novel words were associated with a picture of a fantasy object or creature. Presentations of the different word–picture pairs were quasi-randomized so that the same word–picture pair never appeared two times consecutively. The test phase of the block was an incongruity condition where words were associated with a “wrong” picture. There were two incongruity trials for each of the six words from the training phase. In the incongruity trials, each word was associated with two of the other pictures from the same block. The real words were presented with the two pictures that illustrated a referent for another of the real words (e.g., a picture of a dog was associated once with the word “banana” and once with the word “jacket”), whereas the novel words were presented once each with the two pictures that had been used to illustrate the two other novel words. Pictures from the same block were used in the incongruity trials so that there would not be novelty effects in addition to incongruity effects. There was no marker which indicated where the training phase ended and the test phase of the block began.

The composition of words in each block was quasi-randomized so that there were always three novel and three real word–picture pairs in each block and no word appeared in more than one block. Pairings between specific novel words and pictures were randomized. Real and novel pairs were mixed in the same block rather than being presented in separate blocks because we assumed that the presence of real pairs would emphasize the referential relation between novel words and pictures.

Trials were 2500 msec long with an intertrial interval of 1000 msec. The picture was displayed on the screen during the entire trial while word onset was at 1000 msec. The whole experiment lasted 24.5 min.

EEG Recording and Analysis

The EEG recordings took place in a sound-attenuated room. Visual stimuli were displayed on a 30 × 40 cm computer monitor placed approximately 1 m in front of the participants, and auditory stimuli were presented at an intensity of 70 dB SPL. Participants were video-monitored during the whole session, which lasted approximately 1 hr including familiarization, capping, and impedance measures.

The EEG was recorded with a 0.1/70-Hz band-pass filter at an A/D rate of 500, and amplified with a Neuroscan Nuamps amplifier. Silver–silver chloride electrodes were placed according to the extended international 10–20 system at the following locations: Fp1, Fp2, F3, Fz, F4, FC3, FCz, FC4, C3, Cz, C4, CP3, CPz, CP4, P3, Pz, P4, O1, O2. The vertical electrooculogram (VEOG) was recorded from electrodes placed above and below the right eye. All electrodes were referenced to the average of the left and the right mastoids. Impedances were kept below 5 k Ω for all electrodes.

A zero-phase band-pass filter from 0.3 to 20 Hz was applied to the continuous EEG. Subsequently, epochs of 1500 msec were computed with a prestimulus baseline of 100 msec, and baseline correction (prestimulus interval) was performed. The video recording of participants was used to reject trials where participants were not paying attention to the stimuli. In addition, trials with excessive artifacts were rejected manually. Data from electrodes O1 and O2 were not analyzed due to artifacts.

We calculated ERPs time-locked to both the picture and the spoken word. However, the words were presented after the picture, and thus, it was not until the presentation of the word that violations of trained associations between pictures and words could be assessed. For this reason, we were primarily interested in ERPs to the words, and results regarding ERPs to pictures are only reported briefly. There were at least 10 artifact-free trials in every experimental condition. The mean number of accepted trials for reported ERPs to words were 21.4 ($SD = 5.9$, range 10 to 30) for the last training presentation with novel words, 22.1 ($SD = 5.3$, range 10 to 30) for the last training presentation with real words, 41.7 ($SD = 12.5$, range 18 to 59) for incongruous condition with novel words, and 42.3 ($SD = 11.9$, range 16 to 60) for the incongruous condition with real words.

Statistical Analyses

To test whether children learned the associations between novel words and pictured objects, we compared

ERPs in the trained condition to ERPs in the incongruous condition. The trained condition could not include ERPs to the first few training presentations for each word because, in these presentations, participants had not had sufficient opportunity to establish connections between novel words and pictures. Previous research has shown that children in this age group (18-month-olds) use about three presentations to learn novel word–picture associations under optimal conditions (Houston-Price, Plunkett, & Harris, 2005). As the word learning load in the present study was high compared to the study by Houston-Price et al. (2005), we included only the last (fifth) training presentation in the trained condition because this represented the ERP response where children had been given the most possible opportunities to learn the novel word. Effects for the other presentations in the training phase are not reported in this article. The incongruity condition included the two presentations where words were presented together with a different picture than in the training phase.

Incongruity effects were computed separately for novel and real words using four-way repeated measures ANOVAs with congruity (congruous, incongruous), electrode site (frontal, central, parietal), and laterality (left, midline, right) as within-subject factors and vocabulary group (high, low) as a between-subject factor. In addition to these analyses, we performed corresponding ANOVAs for ERPs time-locked to the pictures using four-way ANOVAs with repetition (picture used in the last training trial, picture used in the incongruity phase), electrode site (frontal, central, parietal), and laterality (left, midline, right) as within-subject factors and vocabulary group (high, low) as a between-subject factor.

Significant interactions were followed up by three-, two-, and one-way subsidiary ANOVAs. Vocabulary group was always included as a between-subjects factor when analyses were not done separately for the two groups. All analyses were carried out for consecutive 200 msec intervals from 0 to 1400 msec. We employed the Greenhouse–Geisser correction for effects with more than one degree of freedom in the numerator. We report unadjusted degrees of freedom and adjusted p values.

RESULTS

Incongruity Effects for Novel Words

For high producers, grand-average waveforms showed a positive peak around 130 msec for both conditions on frontal and central electrode sites (Figure 2). This positive peak was followed by a broadly distributed negativity for the incongruous condition which lasted from about 200 to 400 msec on frontal and central electrode sites, and from about 200 to 600 msec on centro-parietal and parietal electrode sites. A second negative wave, which was also larger in amplitude for the incongruous

condition than the last training trial, started around 700 msec at all electrode sites and lasted until the end of the epoch (1500 msec).

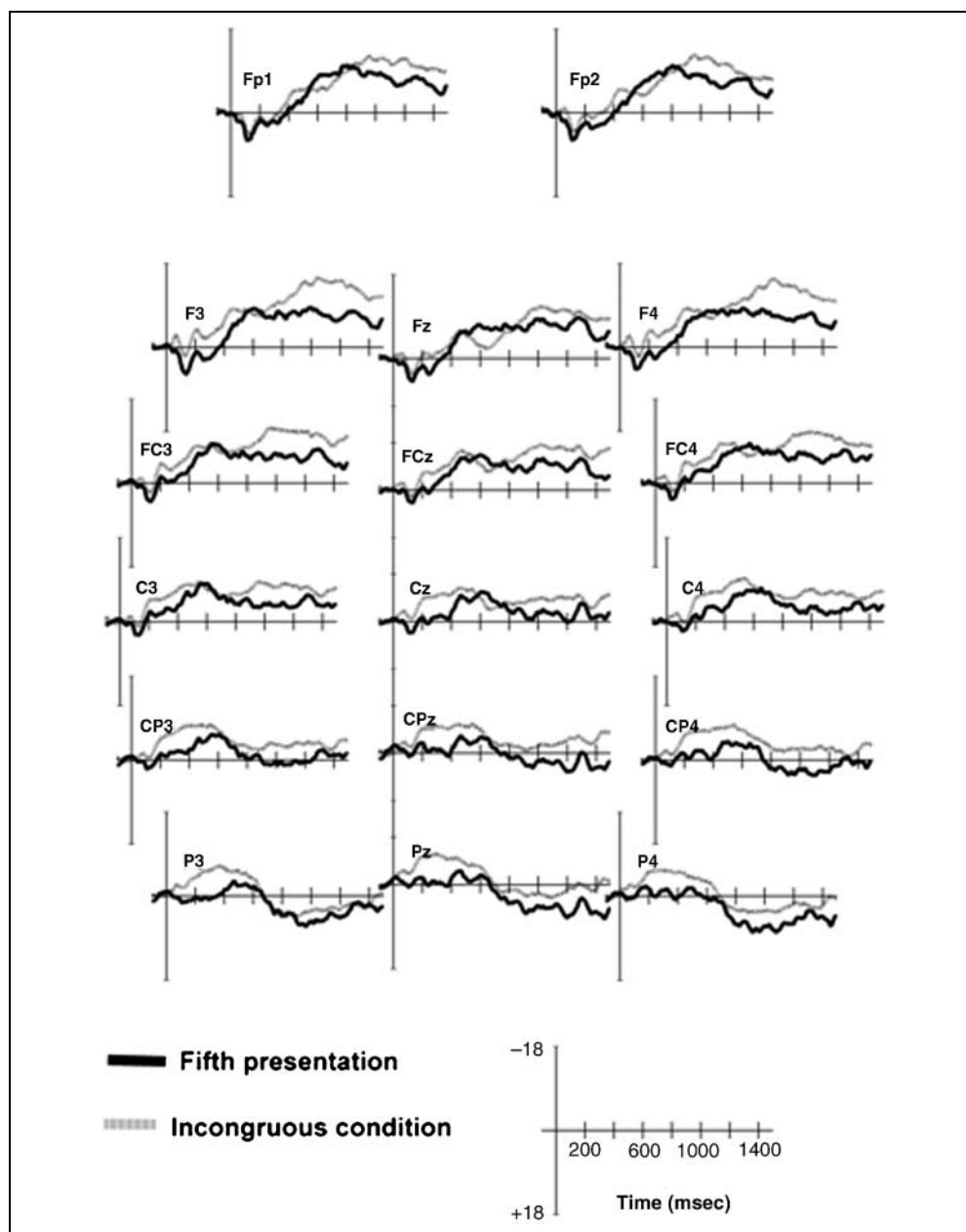
For the low producers, there was a positive peak around 130 msec on all electrodes and a subsequent negativity in the 200–700 msec interval for both conditions (Figure 3). On the left fronto-central, central and parietal electrodes, there was a negativity for the last training trial compared to the incongruous condition starting around 1000 msec.

As shown in Table 1, there was a main effect of congruity in the 200–400 msec interval. Moreover, there were significant interactions between congruity and group in the 1000–1200 and 1200–1400 msec intervals, and a near-significant interaction in the 200–400 msec interval. As a main aim of the present study was to investigate the relation between vocabulary size and fast mapping abilities, separate three-way ANOVAs were run for the high production and the low production groups in all time intervals even though there were only interactions between condition and group in three of the six time intervals.

Analyses revealed a significant effect of congruity for the high producers in the 200–400, 800–1000, and 1000–1200 msec interval, as well as near-significant effects in the 400–600 and 1200–1400 msec intervals. For the low producers, there were no effects of congruity in the 200–1200 msec intervals [$F(1, 18) = 0.00$ – 0.37 , $p = .98$ – $.55$]. In the 1200–1400 msec interval, there was no significant effect of congruity [$F(1, 18) = 1.78$, $p = .20$], but a significant interaction between congruity and laterality [$F(1, 18) = 3.98$, $p = .039$]. A follow-up of this interaction with a two-way ANOVA showed that there was a trend indicating that ERPs were more negative to the training presentation than to the incongruous presentations in central [$F(1, 18) = 3.16$, $p = .09$], but not in frontal [$F(1, 18) = 0.46$, $p = .51$] or parietal [$F(1, 18) = 0.83$, $p = .37$] regions.

Because the planned group analyses showed effects of vocabulary on word–picture congruity for novel words, we conducted a follow-up regression analysis where we tested whether productive vocabulary could predict the amplitude of the N400. The N400 for each electrode was calculated as the difference in amplitude between the last training trial and the incongruity trials. Electrodes O1 and O2 were omitted due to artifacts as for all the other analyses. The average difference score for the remaining 17 electrodes was used in the regression analysis. This variable was calculated for the same time intervals as the other analyses. The linear regression analysis showed a significant relation between productive vocabulary and the amplitude of the N400 to novel words in the 1000–1200 msec interval [$R = .32$, $R^2 = .105$, $F(1, 43) = 4.93$, $p = .03$] and a trend toward a relation in the 1200–1400 msec interval [$R = .26$, $R^2 = .065$, $F(1, 43) = 2.91$, $p = .095$]. The regression weight of .32 in the 1000–1200 msec interval indicated that a

Figure 2. High production group. Novel words. Grand-average waveforms for the last presentation in the training phase and incongruity presentations where the trained association between word and picture was violated. Negative is plotted up on this and all other figures.



higher productive vocabulary was associated with a higher N400 amplitude (Figure 4).

Incongruity Effects for Real Words

Grand-average waveforms for the high production group showed a positive peak around 130 msec for both conditions, followed by a negativity for the incongruous words in the 200–800 msec time window (Figure 5). This negativity, which had a peak around 470 msec, was most pronounced at central and parietal sites, particularly at midline electrodes. On frontal electrodes there was only a slight difference between conditions which was restricted to the 400–600 msec interval.

For the low production group, there was also a positive peak for both conditions around 130 msec (Figure 6). On central electrodes, as well as centro-parietal and parietal electrodes at midline and right sites, there was a negativity for the incongruous condition compared to the congruous condition in the 400–800 msec time window. On most central and parietal electrodes, this negative wave peaked between 500 and 550 msec. On frontal and fronto-central electrode sites, there was no difference between conditions.

Statistical analyses showed a significant main effect of congruity in the 400–600 and 600–800 msec intervals (Table 2). In the 200–400 msec interval, there was no significant effect of congruity [$F(1, 42) = 1.39, p = .25$], but a significant interaction between congruity and

laterality [$F(2, 84) = 3.60, p = .038$]. Follow-up analyses revealed that at there were no significant main effects at left [$F(1, 42) = 0.42, p = .84$], right [$F(1, 42) = 1.58, p = .22$], or midline [$F(1, 42) = 2.60, p = .12$] sites. In the right hemisphere, there was, however, an interaction between congruity and electrode site [$F(2, 84) = 3.69, p = .039$]. Separate ANOVAs for the three different electrode sites in the right hemisphere showed that there was a significant effect of congruity at right parietal [$F(1, 42) = 4.29, p = .045$], but not right frontal [$F(1, 42) = 0.14, p = .12$] or right central [$F(1, 42) = 2.44, p = .12$] electrode sites. In the 200–400 msec interval, there was also a significant interaction between congruity, laterality, and group [$F(2, 84) = 3.44, p = .038$] (see below).

As for the novel words, incongruity effects were calculated separately for the two vocabulary groups. In the 200–400 msec interval, there was no significant main effect of congruity for the high production group [$F(1, 24) = 2.15, p = .16$] and no significant interactions. However, as analyses for the full sample of children showed a significant interaction between congruity, laterality, and group in this time interval, two-way ANOVAs were carried out for the three laterality regions. In the high production group, there was no significant main effect of congruity at left [$F(1, 24) = 2.19, p = .15$], right [$F(1, 24) = 0.79, p = .38$] or midline [$F(1, 24) = 2.52, p = .13$] sites, but at midline sites there was an interaction between congruity and electrode site [$F(2, 48) = 4.58, p = .027$]. Separate one-way ANOVAs for the three

Figure 3. Low production group. Novel words. Grand-average waveforms for the last presentation in the training phase and incongruity presentations where the trained association between word and picture was violated.

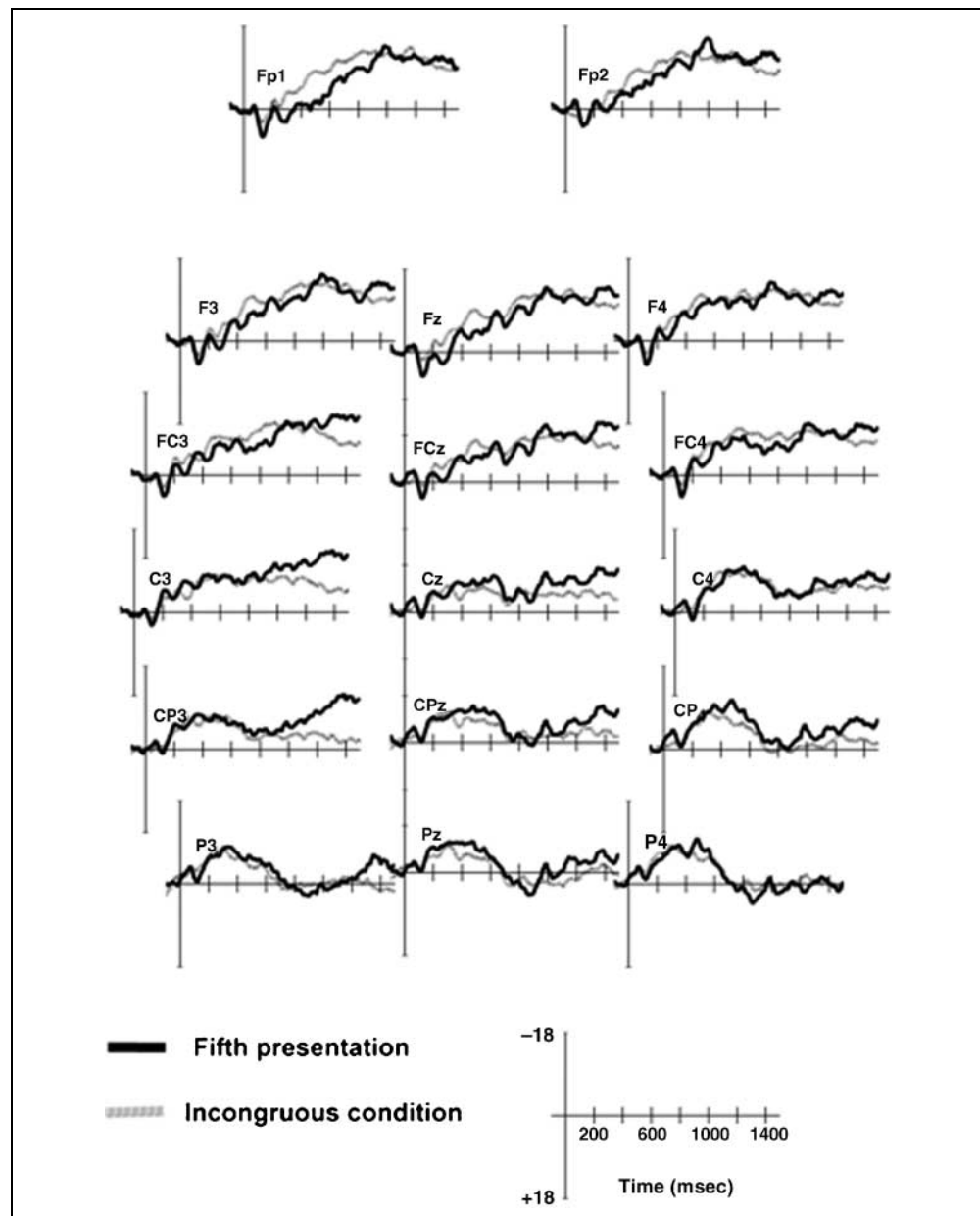


Table 1. Incongruity Effects for Novel Words

Time (msec)	Congruity, All Subjects, $F(1, 42)$	Congruity*, Group, $F(1, 42)$	Congruity, High Production Group, $F(1, 24)$	Congruity, Low Production Group, $F(1, 18)$
200–400	4.53*	(3.58, $p = .068$)	9.93***	
400–600			(3.40, $p = .078$)	
600–800				
800–1000			5.10*	
1000–1200		4.94*	7.19**	
1200–1400		5.44**	(4.09, $p = .055$)	

Four-way ANOVAs with congruity, electrode site, and laterality as within-subject factors, and vocabulary group as a between-subject factor. Separate three-way ANOVAs for each production group with the same within-subject factors.

* $p < .05$.

** $p < .03$.

*** $p < .01$.

midline regions revealed a significant effect of congruity at central [$F(1, 24) = 4.29, p = .049$] and parietal [$F(1, 24) = 4.66, p = .041$] midline sites, but not at the frontal midline [$F(1, 24) = 0.05, p = .83$]. For the low production group, there was no main effect of congruity in the three-way ANOVA [$F(1, 18) = 0.10, p = .75$], but a significant interaction between congruity and laterality [$F(2, 36) = 5.98, p = .01$]. Separate analyses for the different laterality regions showed no effects for left [$F(1, 18) = 1.10, p = .31$], right [$F(1, 18) = 0.75, p = .40$], or midline [$F(1, 18) = 0.56, p = .47$] sites.

In the 400–600 msec interval, there was a significant main effect of congruity for the high-vocabulary group [$F(1, 24) = 6.73, p = .02$] and no interactions. For the low production group, there was a near-significant main

effect of congruity [$F(1, 18) = 3.56, p = .075$] and an interaction between congruity and electrode site [$F(2, 36) = 7.40, p < .001$] and between congruity and laterality [$F(2, 36) = 4.65, p = .02$]. Follow-up analyses for the three electrode sites showed that there was a significant effect of congruity at central [$F(1, 18) = 4.90, p = .04$] and parietal sites [$F(1, 18) = 7.90, p = .01$], but not at frontal sites [$F(1, 18) = 0.11, p = .75$]. Analyses for the laterality dimensions showed that there was no effect of congruity in the left hemisphere [$F(1, 18) = 0.53, p = .48$]. In the right hemisphere, there was a near-significant effect of congruity [$F(1, 18) = 4.16, p = .06$] and a significant interaction between congruity and electrode site [$F(2, 36) = 15.88, p < .001$]. One-way ANOVAs for the different sites in the right hemisphere revealed a significant effect at right parietal sites [$F(1, 18) = 12.79, p < .001$], a near-significant effect at right central sites [$F(1, 18) = 4.16, p = .06$], but no effect at right frontal sites [$F(1, 18) = 0.25, p = .62$]. At midline sites, there was a significant main effect of congruity [$F(1, 18) = 5.45, p = .03$].

In the 600–800 msec interval, there was a near-significant main effect of congruity for the high production group [$F(1, 24) = 4.27, p = .050$], and no significant interactions. For the low production group, there was also a trend toward an effect of congruity [$F(1, 18) = 3.15, p = .09$] and a significant interaction between congruity and laterality [$F(2, 36) = 4.38, p = .02$]. This interaction was followed up by two-way ANOVAs for the three laterality dimensions. In the left hemisphere, there was no effect of congruity [$F(1, 18) = 0.47, p = .50$]. In the right hemisphere, there was a near-significant main effect of congruity [$F(1, 18) = 4.09, p = .06$] and a significant interaction between congruity and electrode site [$F(2, 36) = 8.22, p < .001$]. One-way ANOVAs revealed that although there were no effects at right frontal [$F(1, 18) = 0.35, p = .83$] or right central [$F(1, 18) = 0.68, p = .42$] sites, there was a significant effect of congruity at right

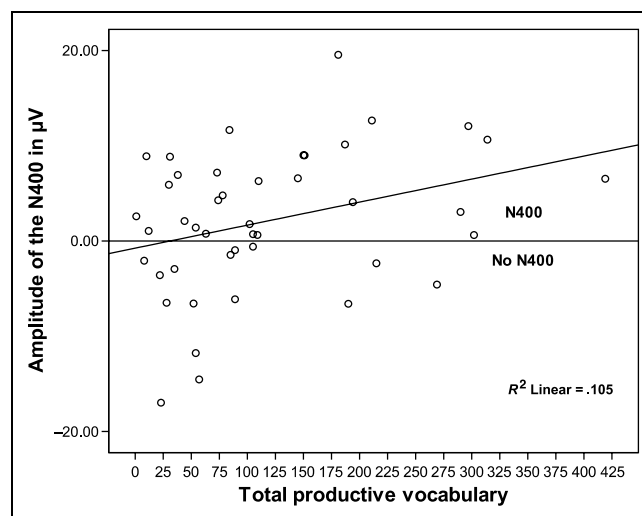
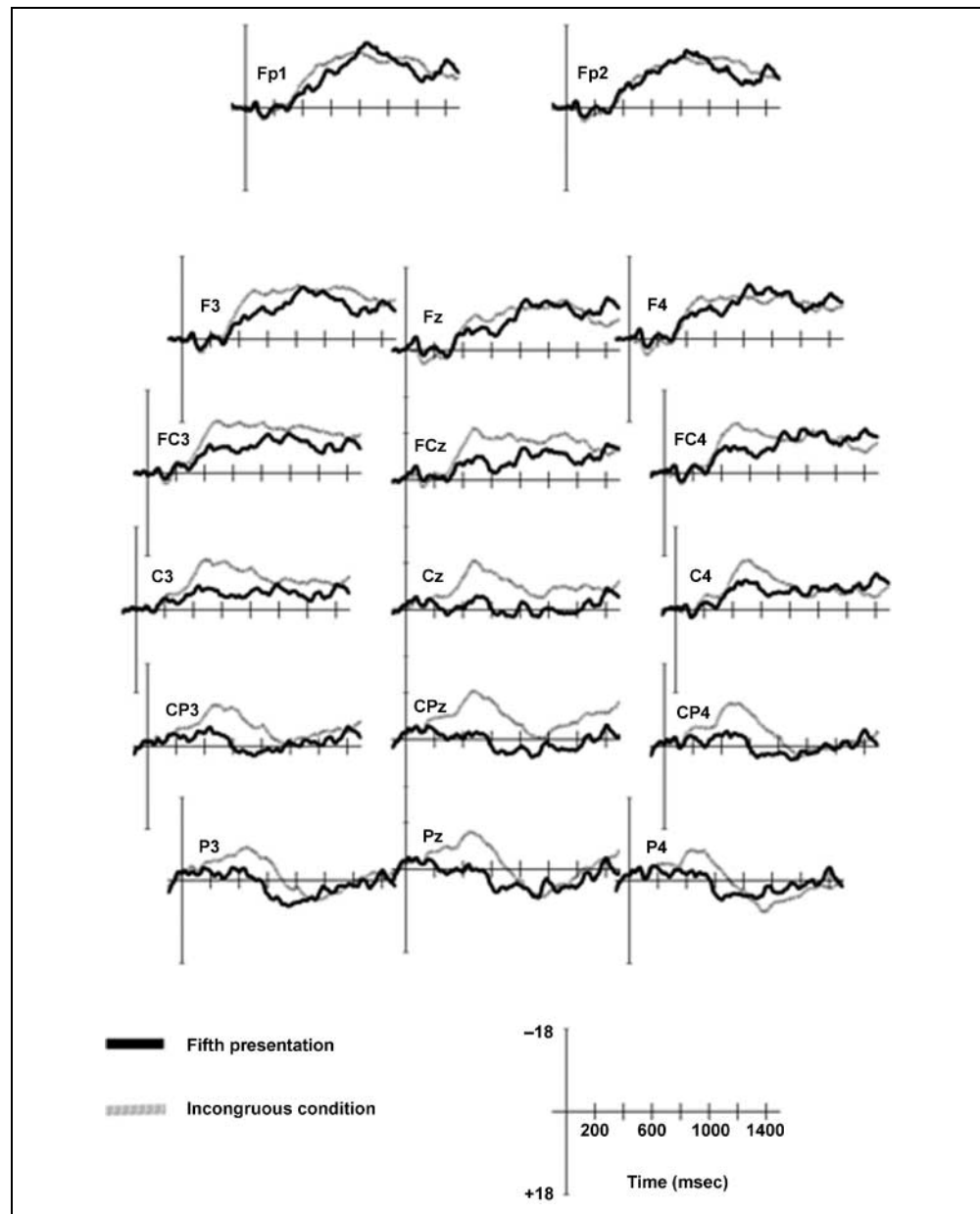


Figure 4. Novel words. Scatterplot of total productive vocabulary size and N400 amplitude in the 1000–1200 msec interval with regression line fitted to data. Note that a positive value on the y-axis represents the presence of an N400 and a negative value represents the absence of an N400.

Figure 5. High production group. Real words. Grand-average waveforms for congruous (presentation five) and incongruous picture–word pairs.



parietal sites [$F(1, 18) = 9.80, p = .01$]. At midline sites, there was a significant main effect of congruity [$F(1, 18) = 4.60, p = .046$]. There were no significant effects in later time intervals.

ERPs Time-locked to Pictures

Grand-average waveforms time-locked to the presentation of the pictures are shown in Figures 7, 8, 9, and 10. Statistical analyses for novel pictures show that there was a significant effect of picture repetition (last training trial compared to the subsequent incongruity trials) in the 200–400 msec interval [$F(1, 43) = 4.84, p = .03$] and in the 400–600 msec interval [$F(1, 43) = 6.32, p = .02$]. In these time intervals, the ERP to the picture became more positive with repetition. There were no significant

or near-significant interactions between picture repetition and vocabulary group. For pictures of real objects, there were no significant effects of repetition. There was, however, a trend toward an interaction between picture repetition and vocabulary group in the 800–1000 msec interval [$F(1, 42) = 3.98, p = .052$] and in the 1200–1400 msec interval [$F(1, 43) = 3.92, p = .054$]. Separate analyses for the two production groups revealed that in the 800–1000 msec interval there was a trend for high producers that ERPs became more positive with repetition in the 800–1000 msec interval [$F(1, 24) = 3.64, p = .068$], whereas for low producers there was no significant effect of repetition [$F(1, 18) = 0.95, p = .34$]. In the 1200–1400 msec interval, there was significant effect of repetition for high producers [$F(1, 24) = 1.31, p = .26$], whereas there was a trend that

ERPs became more negative with repetition for low producers [$F(1, 18) = 2.84, p = .11$].

DISCUSSION

In the current study, we demonstrated an electrophysiological procedure for assessing receptive word learning in young children. This procedure, which involved training of associations between words and referents, and subsequent violation of these associations, yielded evidence of fast mapping in 20-month-olds. Moreover, results revealed effects of vocabulary size on fast mapping performance. The specific effects found in the current experiment and implications of these for the debate about the underlying causes of the vocabulary spurt will be discussed in turn.

Semantic Incongruity Effects

For novel words, children in the high production group displayed a negativity on those trials where the trained word-referent association was broken (incongruous condition) compared to the last training trial (congruous condition). The broad scalp distribution and the timing of this response was similar to the N400 incongruity effect to word–picture mismatches in previous studies of this age group (Torkildsen et al., 2006; Mills, Conboy, et al., 2005; Friedrich & Friederici, 2004), suggesting that it represents an N400-like effect. Children in the low production group did not show any difference between the congruous and incongruous condition.

A possible interpretation of these findings is that high producers, but not low producers, were capable of fast

Figure 6. Low production group. Real words. Grand-average waveforms for congruous (presentation five) and incongruous picture–word pairs.

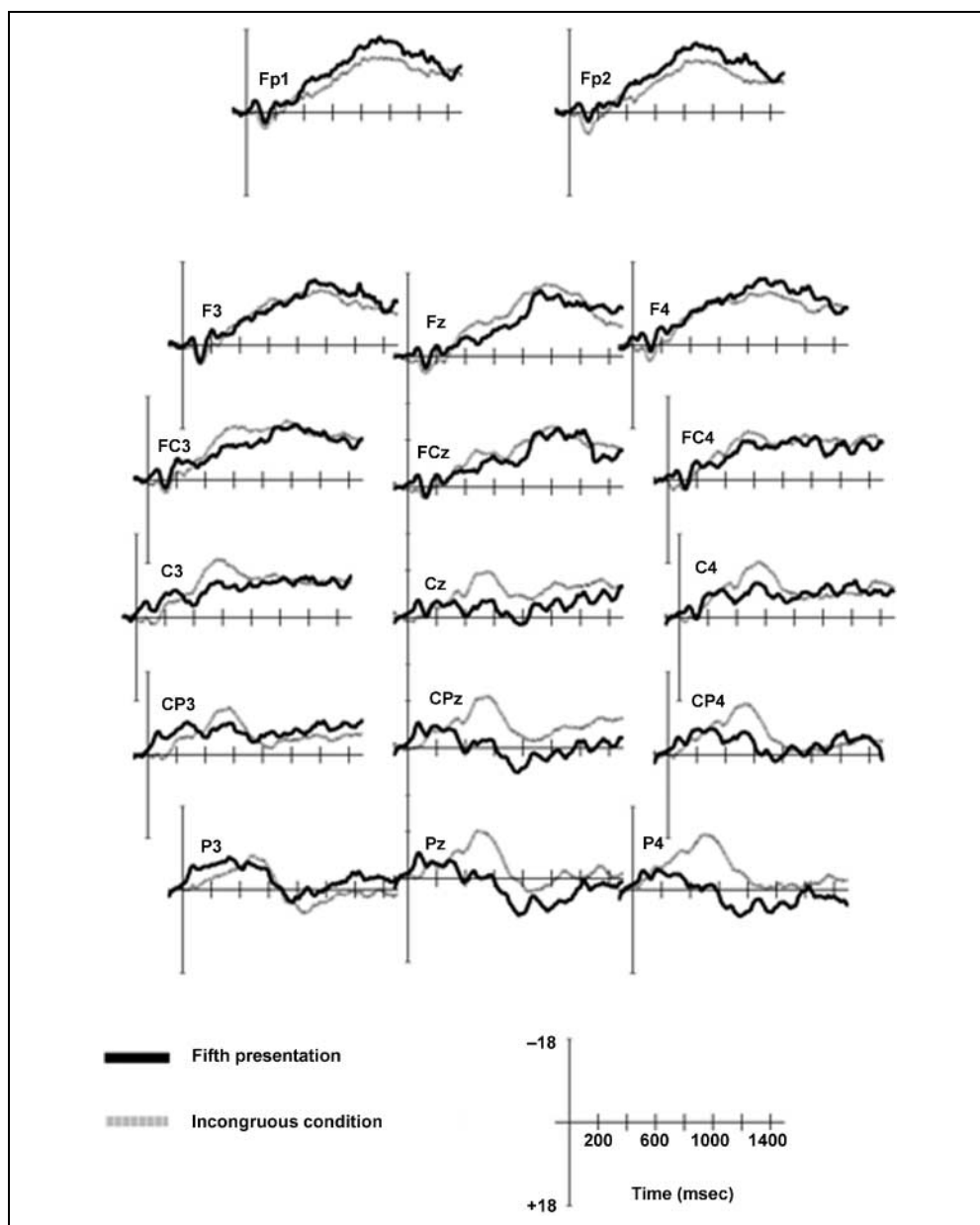


Table 2. Incongruity Effect for Real Words

Time (msec)	All Subjects		High Production Group		Low Production Group	
	Congruity <i>F</i> (1, 42)	Local Effects <i>F</i> (1, 42)	Congruity <i>F</i> (1, 24)	Local Effects <i>F</i> (1, 24)	Congruity <i>F</i> (1, 18)	Local Effects <i>F</i> (1, 18)
200–400		Right parietal: 4.29*		Central midline: 4.29* Parietal midline: 4.66*		
400–600	9.78***		6.73**		(3.56, <i>p</i> = .075)	Central: 4.90* Parietal: 7.90** Midline: 5.45*
600–800	7.23**		(4.27, <i>p</i> = .050)		(3.15, <i>p</i> = .093)	Midline: 4.60* Right parietal: 9.80***

Four-way ANOVAs with congruity, electrode site, and laterality as within-subject factors, and vocabulary group as a between-subject factor. Separate three-way ANOVAs for each production group with the same within-subject factors. Main effects and local effects after follow-ups of interactions with two- or one-way subsidiary ANOVAs. There were no significant effects after 800 msec.

**p* < .05.

***p* < .03.

****p* < .01.

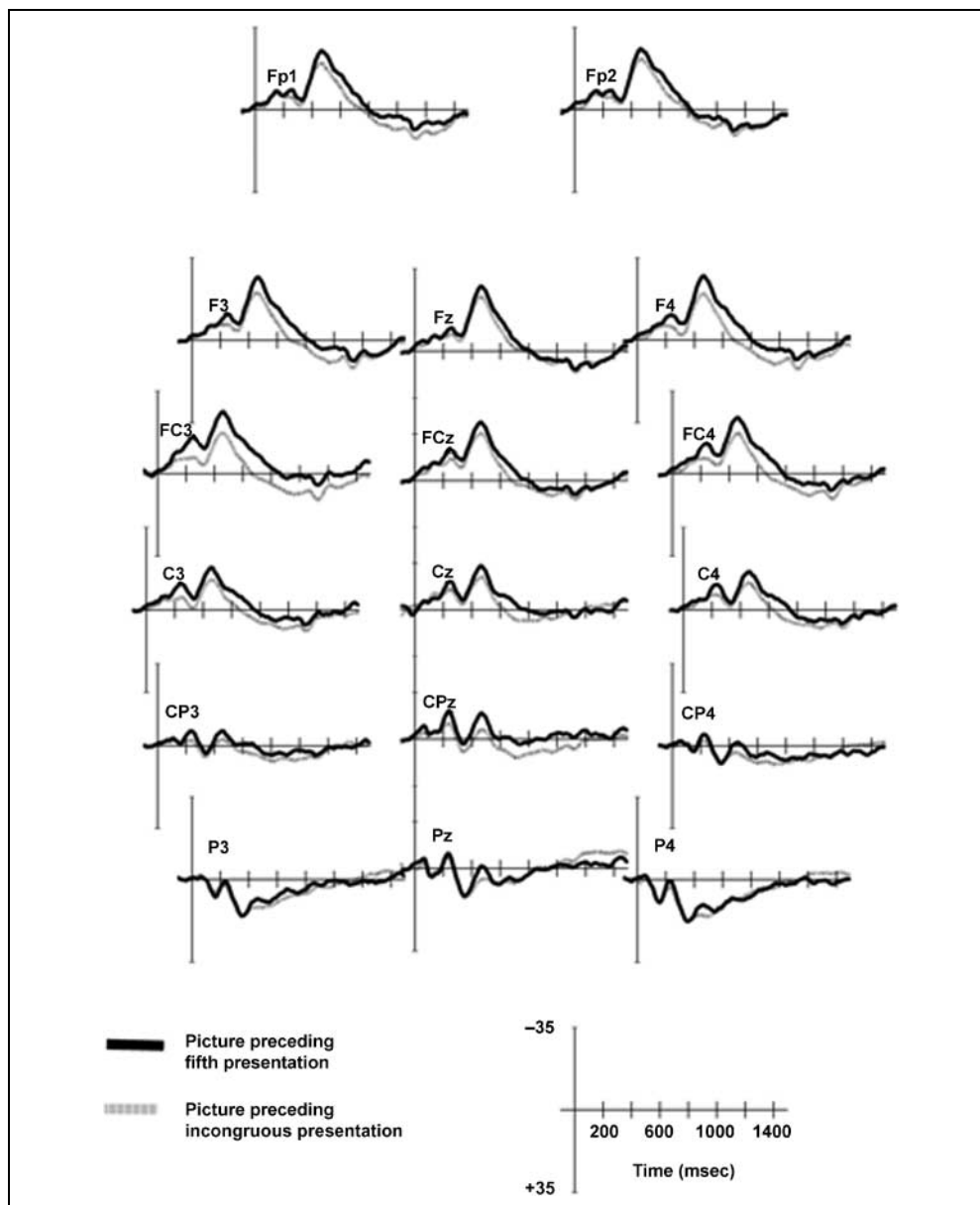
mapping between novel words and referents. An alternative explanation is that the low producers had made the fast mapping between words and referents, but that the mechanisms indexed by the N400 were not yet matured in this group. The latter explanation would be consistent with two previous studies of children with low vocabularies. Friedrich and Friederici (2006) retrospectively compared ERPs of 19-month-olds who were found to have very low expressive language scores on the word or sentence production part of a German language test at 30 months to children who displayed age-appropriate productive language abilities at this age. They reported that 19-month-olds with low productive language scores 11 months later did not display an N400 response to incongruous picture–word pairs, whereas an age-matched control group did show an N400. As the low-vocabulary children did exhibit an early lexical–phonological priming effect for congruous words, the authors argued that the lack of an N400 could not be due to missing lexical or semantic knowledge, and thus, it appeared that the N400 mechanisms had not yet matured in this group. In a similar vein, Torkildsen, Syversen, Simonsen, Moen, and Lindgren (2007a) found that picture–word mismatches elicited an N400-like incongruity effect in typically developing 20-month-olds, but not in a group of 20-month-olds at familial risk for dyslexia who also had lower productive vocabularies than the no-risk group. Moreover, in that study, we found an enhanced early lexical priming effect in the at-risk group, which indicated that the at-risk children had acquired the vocabulary used in the test and were able to recognize correct referents for the pictures. However, an explanation in terms of lacking N400 mechanisms must be

excluded in the present study, as children in the low production group did show an N400-like incongruity effect for real words which were paired with an incorrect picture.

Although the low production group clearly showed the presence of N400 mechanisms, it is unclear exactly what underlay the low producers' failure to map between novel pictures and words. However, as there were no significant differences between the vocabulary groups in the processing of the novel pictures, it is likely that most of the difficulties for the low producers concerned the subsequent stages of fast mapping, that is, processing the novel word forms and forming associations between these and the pictures.

In a follow-up regression analysis, we found that in one of the tested time intervals, productive vocabulary size predicted the amplitude of the N400 to violations of trained picture–word associations. The direction of the effect showed that a larger productive vocabulary was associated with increased amplitude of the N400 for novel words. This finding is in line with a previous toddler study of the N400 to incongruities involving real words by Friedrich and Friederici (2004). They divided children into two groups on the basis of the number of words used in the experiment that parents reported as comprehended. Results showed that the high comprehension group displayed a larger and earlier N400 than the low comprehension group. However, in the study by Friedrich and Friederici, the group difference might have been due to the absence of the N400 in some of the low-vocabulary children, rather than the generally lower amplitude of the component. Moreover, it should be kept in mind that for older children, the relationship between linguistic abilities and N400 amplitude tends to go in the opposite direction than what

Figure 7. High production group. Novel words. Grand-average waveforms for pictures preceding the fifth presentation of words (last training trial) and pictures preceding incongruous words. Note that the scale of the y-axis in the grand averages for pictures is different from that in grand averages to words.



was observed in the present study and that of Friedrich and Friederici. Studies comparing adults and children, and studies of children of different ages (from 5 years upward) have shown that the amplitude of the N400 tends to decrease with age (Hahne, Eckstein, & Friederici, 2004; Jouttonen, Revonsuo, & Lang, 1996; Holcomb, Coffey, & Neville, 1992). Furthermore, a study comparing children with typical language development to children with language impairment demonstrated a larger N400 for the language-impaired children (Neville, Coffey, Holcomb, & Tallal, 1993). There are at least two possible explanations for the above set of findings. One is that there is a positive relation between linguistic abilities and the amplitude of the N400 in very early language development, but that this relation is altered with further development. Another possibility is that the association with amplitude observed in the current study was due to a relation be-

tween vocabulary and the presence of the N400 rather than the absolute amplitude of the component. Further research is needed to clarify this issue.

For real words, both high and low producers showed a negativity in the incongruous condition compared to the congruous condition. However, as opposed to the broadly distributed incongruity effect which high producers displayed for mismatches of recently learned word–picture associations, the incongruity effect for real words was most prominent at central and parietal electrode sites for both groups of children, and thus, resembled the distribution of the auditory N400 in adults (see e.g., Holcomb & Neville, 1990). The difference in scalp distribution between incongruity effects for real and novel words is consistent with findings by Mills, Conboy, et al. (2005), which indicate that increased experience with individual words lead to more focalized brain responses.

With regard to the latency of the incongruity effect for real words, there were some differences between production groups. High producers showed a significant effect of congruity already in the 200–400 msec interval, a robust main effect in the 400–600 msec interval, but only a marginal effect in the 600–800 msec interval. Low producers, on the other hand, showed no effect of congruity in the 200–400 msec interval, and displayed effects that were equally strong in the 400–600 and 600–800 msec intervals. The observed latency difference is consistent with previous eye-tracking studies showing that children with high production vocabularies identify familiar words faster than children with low vocabularies (Fernald, Perfors, & Marchman, 2006; Fernald, Swingley, & Pinto, 2001; Zangl, Klarman, Thal, & Bates, 2001), and previous ERP studies reporting that the N400 is earlier

in children with larger vocabularies than in children with smaller vocabularies (Torkildsen et al., 2006; Friedrich & Friederici, 2004). However, when interpreting the results of both the current experiment and the above previous studies, it is difficult to determine whether group effects are due to more efficient general word processing in the high-vocabulary groups or greater familiarity with the real-word stimuli. In the present study, the group difference in the number of stimulus words reported to be comprehended was relatively small, but this does not preclude large differences between vocabulary groups in the *degree* of real-word familiarity.

Production groups also differed in the topographical distribution of the incongruity effect for real words, with the effect for low producers being more right-lateralized than for high producers. We do not have an explana-

Figure 8. Low production group. Novel words. Grand-average waveforms for pictures preceding the fifth presentation of words (last training trial) and pictures preceding incongruous words.

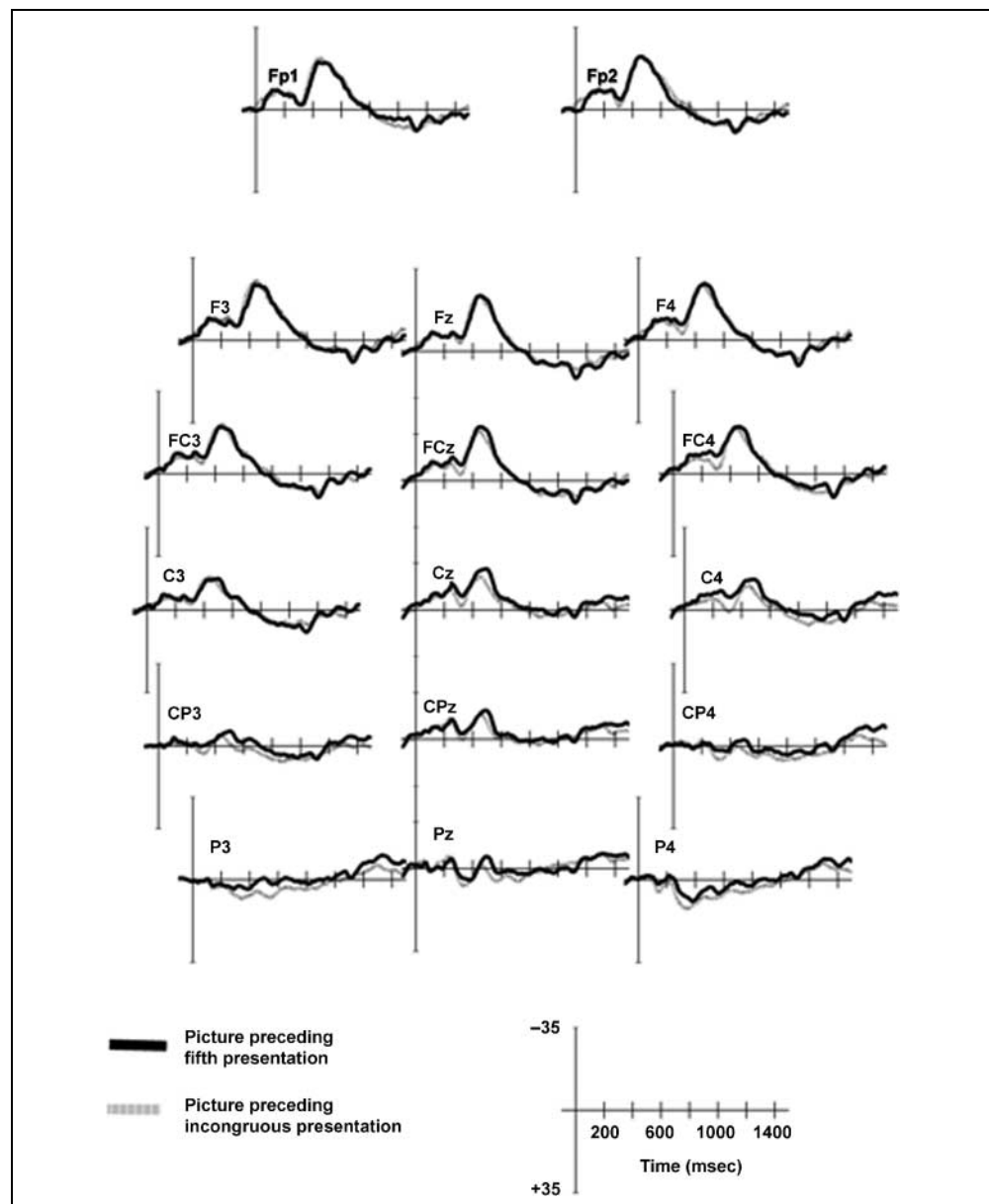
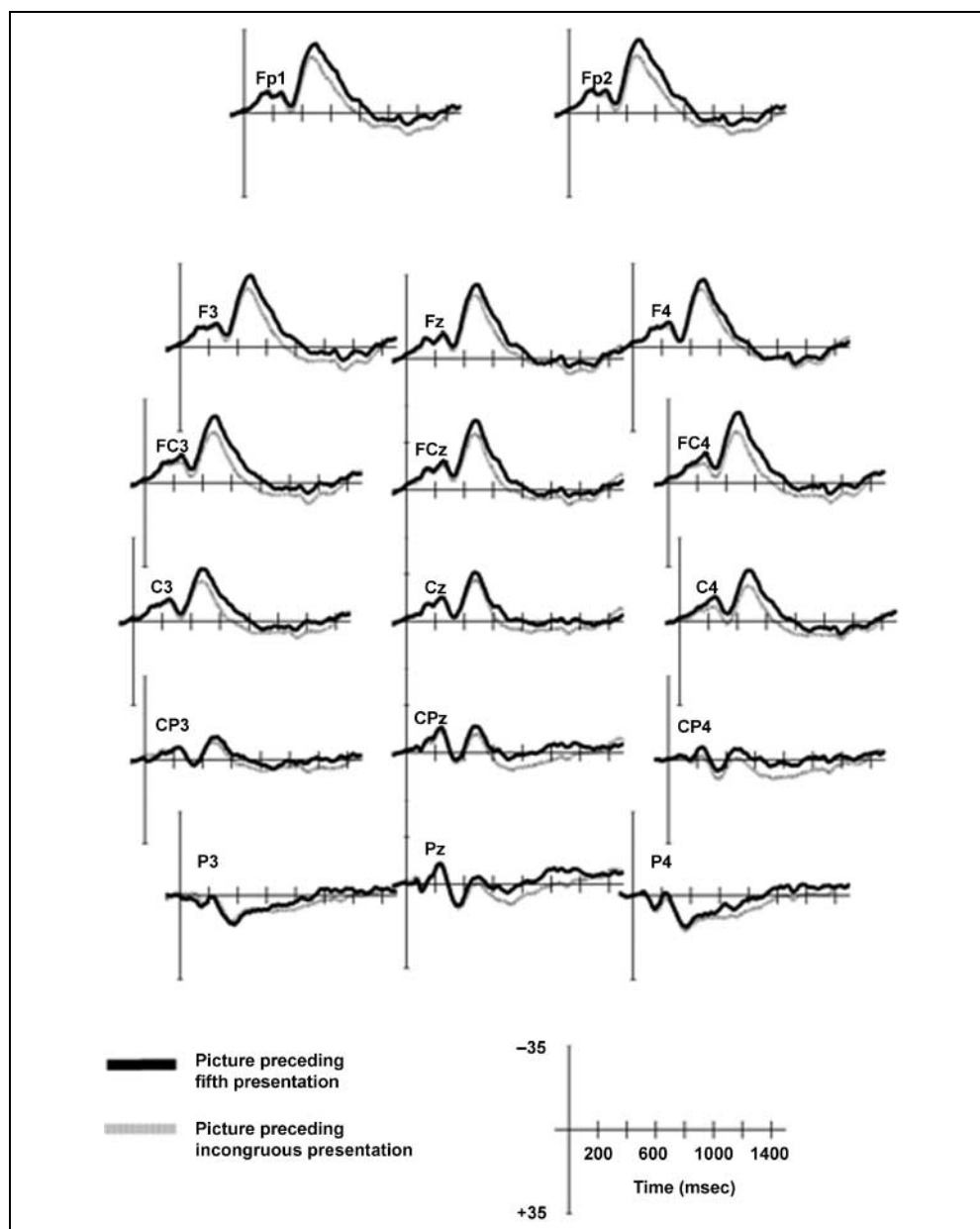


Figure 9. High production group. Real words. Grand-average waveforms for pictures preceding the fifth presentation of words (last training trial) and pictures preceding incongruous words.



tion for this topographical difference. The observed pattern stands in opposition to the result of Friedrich and Friederici (2004), who found that 19-month-olds with low comprehension vocabularies displayed only a small N400 in the left hemisphere, whereas 19-month-olds with a high comprehension vocabulary showed a broadly distributed N400.

The Productive Vocabulary Spurt and Receptive Fast Mapping

Although some earlier research has suggested that there is an important link between fast mapping skills and the vocabulary spurt (Golinkoff et al., 1992; Markman, 1989), a number of recent studies have found that children are able to fast map about half a year before the productive

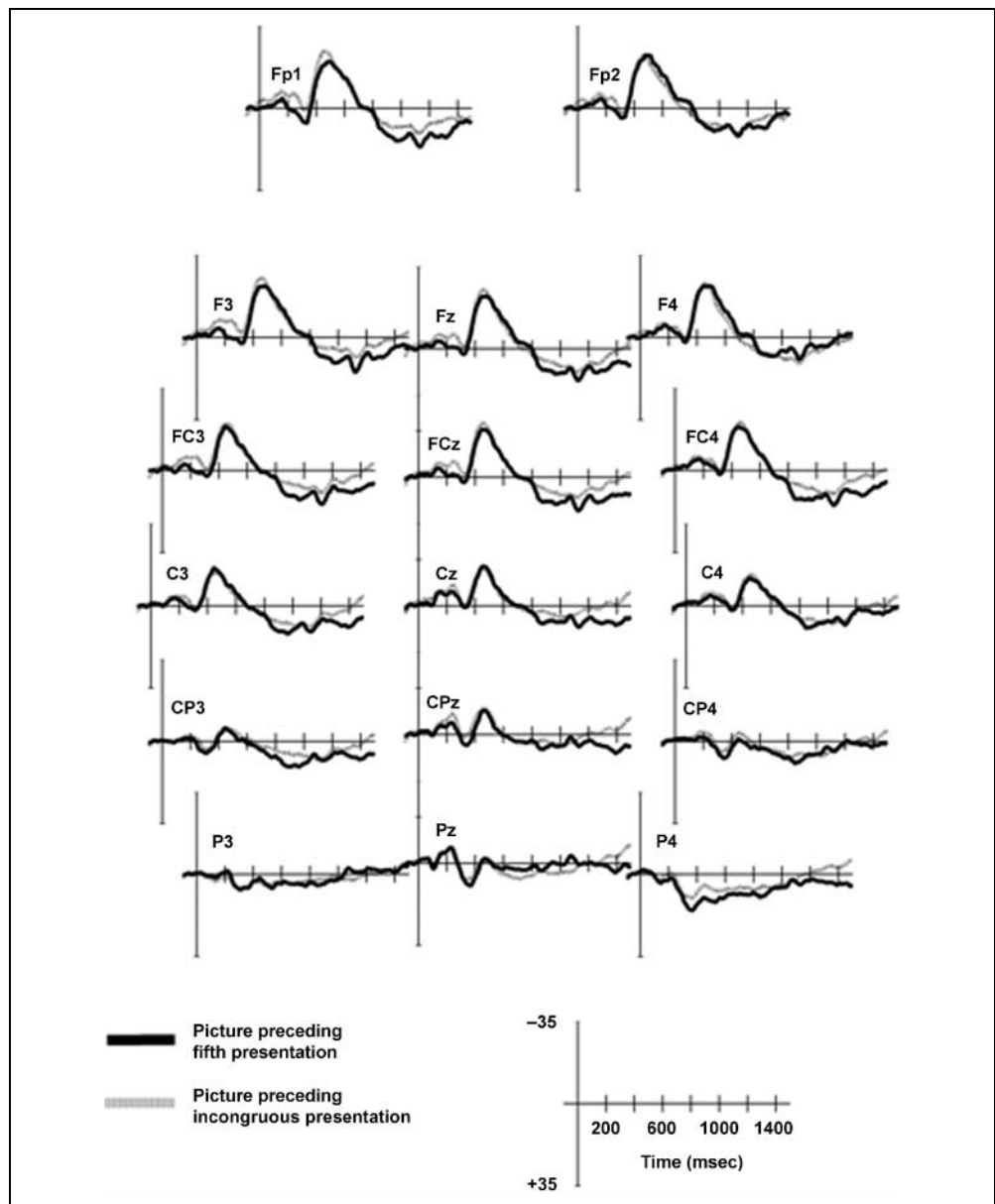
vocabulary spurt usually takes place (Schafer & Plunkett, 1998; Werker et al., 1998; Woodward et al., 1994). The latter findings have been used to suggest that there is a spurt in receptive language already around 13–15 months of age (Werker et al., 1998), and consequently, that the productive vocabulary spurt at the end of the second year may not result from general changes in language processing skills, but rather from changes specific to production, such as improved articulatory control or increased motivation to communicate (Ninio, 1995; Woodward et al., 1994). This argument has been strengthened by a preferential looking study which did not find a relation between fast mapping skills and productive vocabulary size in children around the age of the vocabulary spurt (Tan & Schafer, 2005), and by an ERP study which found no reliable differences between 20-month-olds with high and

low vocabularies in the processing of novel words (Mills, Plunkett, et al., 2005).

In the present study, we found that 20-month-olds with high productive vocabularies, but not 20-month-olds with low productive vocabularies, showed evidence of fast mapping between novel words and referents. It is, however, unlikely that the low producers tested in the current study were generally incapable of fast mapping, as they were several months older than the children who have been shown capable of fast mapping in visual preference paradigms (Schafer & Plunkett, 1998; Werker et al., 1998; Woodward et al., 1994). A more reasonable interpretation of the results is that the fast mapping load in the present study was too high for the low producers. There are several factors which have been shown to influence fast mapping success in toddlers. These include the number of exposures to each pairing between

word and referent, the number of words to be learned in the experimental session, the type of referents used (e.g., still images, moving images, or 3-D objects), whether the referents for the novel words are familiar or not, and the presence of social cues such as pointing and eye gaze. In a recent preferential-looking study, Houston-Price et al. (2005) showed that 18-month-olds were capable of fast mapping in just three exposures. However, their experiment involved only two novel labels, and referents were highly familiar to participants. The present study involved 30 novel words, presented five times each, and referents were still images that had never been seen before by the participants. In this regard, the current experiment was difficult compared to earlier fast mapping tasks used with children in their second year of life. Thus, although children in both groups were most likely able to fast map in the sense that they could learn associations between

Figure 10. Low production group. Real words. Grand-average waveforms for pictures preceding the fifth presentation of words (last training trial) and pictures preceding incongruous words.



words and referents in relatively few trials, it appears that the fast mapping capability of the low producers was not efficient enough for the present task.

Although it may be that children undergo a spurt in receptive word learning abilities around 13 to 15 months of age (Werker et al., 1998; Benedict, 1979), results of the present study suggest that receptive fast mapping abilities are by no means “in place” by that age. More specifically, our results indicate that there are substantial differences in receptive fast mapping efficiency between typically developing children who appear to have undergone a productive vocabulary spurt and typically developing children who appear not to have reached this productive spurt. Thus, findings of the present study point to the possibility that it is not only development in purely productive abilities, such as improvement of articulatory skills (Woodward et al., 1994) or gains in social motivation (Ninio, 1995), that may contribute to the dramatic changes in productive abilities that normally take place during the second half of the second year. We hypothesize that improvement in fast mapping abilities may be an important factor underlying the vocabulary spurt. This hypothesis is in accordance with studies showing a close relation between productive and receptive vocabularies in the second year of life (Harris, Yeles, Chasin, & Oakeley, 1995; Reznick & Goldfield, 1992). A natural next step to investigate a possible causal relation between developments in productive vocabulary and receptive word learning would be a longitudinal study assessing whether changes in productive vocabulary go together with changes in receptive fast mapping abilities at different points in time.

When interpreting the results of the present experiment and related studies of fast mapping in young children, however, it should be kept in mind that fast mapping is not full word learning. It has been claimed that fast mapping might operate only in controlled, simplified situations, and only for some types of words (Deák & Wagner, 2003). Future studies may provide more insight into how children elaborate their word meanings in the course of development and how the completeness and accuracy of word meanings relate to vocabulary size.

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