DEPARTMENT OF PSYCHOLOGY
PSYKOLOGEXAMENSUPPSATS

Examining the link between productive vocabulary and the shape bias: An ERP study

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ACKNOWLEDGEMENTS

I am grateful to my supervisor Magnus Lindgren who shared his wealth of knowledge and provided guidance and support during the writing of this thesis. I would like to express a special thanks to Kristina Magnusson for the project design and for all her practical help. Finally, this study could not have been possible without the generous nature of the parents and children who agreed to participate in it.

ABSTRACT

It is during a child's second year that the rate of word learning increases drastically and they start to pay more attention to the property of shape when categorizing new objects. The present study set out to investigate the relationship between productive vocabulary size and the shape bias when children learn novel words. In order to better understand the neural mechanisms behind this process, event related brain potentials (ERPs) were recorded in an experiment with a group of 14 twenty-month olds. They were shown a series of real and novel picture/word pairs presented as a whole picture, a cluster of details or a black silhouette. After associations were learned, the objects were paired with the wrong names to see if a difference between congruent and incongruent presentations as indexed by N400 amplitudes could be discerned. The N400 is a component that is known to reflect the mechanisms underlying semantic integration and signifies that learning has taken place.

Results showed that subjects with high productive vocabularies displayed an N400 incongruity effect for silhouette presentations (that represent shape) for both real words and pseudowords, indicating that children in the second year with large productive vocabularies show a sensitivity to shape when learning associations between new words and their referents.

Key Words: ERP, N400, vocabulary spurt, shape bias, pseudowords, toddlers, silhouette

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Introduction

While the second year of life is often referred to as the "terrible twos", it is also a very dramatic time in a child's life as far as developmental advances are concerned. The child is just crossing the threshold from infancy to toddlerhood and is eager to learn about the interesting and exciting world around them. One key aspect of development in the second year is that of being able to communicate, which is a fundamental process that has its basis in learning language. During this period, a child's vocabulary increases at a remarkable rate as they learn to associate words with meaning. Examining this linguistic formation gives us insight into early childhood conceptual and semantic representations. There is, however a surprising lack of research into the underlying mechanisms of language acquisition with this age group, especially on a neural level.

Children typically go through several developmental stages of language acquisition during their first 3 years although there is much variation between individuals. The first indication that a child understands some of what is being said happens at around 7 months, the (slow) beginning of word production at around a year and then a rapid increase beginning at 16-18 months. Word combinations appear around 20 months and by two years of age the child knows some grammar and types of words other than nouns. By age three, most normally developed children will have mastered the basic structure of their native language and be able to say hundreds of words (Fenson et al., 1994).

Measurements with EEG and ERPs

Electroencephalography is a method for recording electrical activity in the brain by placing electrodes on the scalp. Electrophysiological reactions to stimuli can be measured which may provide more complex information and enable the researcher to discover subtle processing distinctions that are not apparent with behavioral techniques. Since it can be hard to distinguish where or what is happening in the brain, continuous EEG waveforms can be separated and averaged to reflect event related potentials (ERPs), which are neural responses to a particular event. Being able to average these temporal waveforms eliminates background noise and other brain activity not related to the specific response to a stimulus. ERPs can then be analyzed to pinpoint specific cognitive effects and are well-suited to address investigations regarding what part of the brain is stimulated during a specific task, and for which behavioral methods alone are not adequate. Sometimes, however it can be hard to interpret the large sets of data that ERP experiments generate (Luck, 2005).

Research into early childhood development has, in recent years broadened to include the examination of associated neural components through studies with ERPs. The union between experimental psychology and electrophysiological methods for examining language development in young children can be seen as an important complement to behavioral approaches since relying only on observations to understand complex cognitive mechanisms limits the scope of potential knowledge.

The use of ERPs is well suited to studies with children because it is non-invasive. Another advantage of using ERPs is that you do not need observable responses from subjects (for example infants, who have limited language and motor skills). Nor does the subject necessarily have to understand and follow directions during the experiment (Torkildsen, 2008).

The N400

There are several important and well studied ERP components that have names that denote their position, latency and polarity in the waveform. The one most significant to this study is the N400.

The N400, which peaks around 400 ms in adults, is a negative wave that is activated in the left temporal lobe, is strongest over parietal and centrally placed electrodes and has a slightly larger amplitude in the right hemisphere (Luck, 2005). It is a language related ERP component that reflects the mechanisms of semantic integration. While the N400 is not an exclusively linguistic effect, it is especially sensitive to words, sounds and pictures. The N400 measure is associated with "a number of verbal processing phenomena that depend upon expectancy: semantic priming, lexical decision making, word recognition" (Hillyard & Kutas, 1983, p. 54). N400 effects are largest when greater mental effort is required and when there is an expectancy violation (Kutas & Federmeier, 2000).

The N400 is however, subject to a priming effect, which means that words that are relatively common have been recently repeated or are generally expected evoke a reduced amplitude, while the opposite conditions elicit a larger N400 effect. Suppose you hear the sentence ”I went into the kitchen to eat a sandwich”. Your brain would not treat this sentence as out of the ordinary. On the other hand, the sentence ”I went into the kitchen to eat a *chair*” would elicit a large N400 response because the word *chair* was unexpected.

The N400 component has been used with good results in previous research into the areas of object recognition and lexical-semantic processing in children (e.g. Friedrich & Friederici, 2004, 2005a, 2006, 2010; Torkildsen, 2007a, 2008). Friedrich and Friederici (2005b) explored different types of words to see if the brain distinguishes between real words, pseudowords and nonwords. Words that "obey the phonetic, prosodic, and phonotactic rules of a given language" are considered phonotactically legal and can elicit an N400 response because they are perceived by the brain as “potential word candidates” just like real words (p. 1786). Pseudowords are an example of this. It is interesting to note however, that the N400 effect is not observed for “phonotactically illegal” words *(nonwords*), which are words that violate the rules of a given language.

Many of the ERP studies with children up to 36 months have used a match-mismatch paradigm to elicit an N400 effect. This is when a picture is paired with either its correct name (congruent presentation) or incorrect name (incongruent presentation). The use of real words can be seen as a way to test whether children recognize familiar (real) words by reacting when a semantic association is violated and is frequently used as a control measure. Some studies have also incorporated pseudowords into their design in order to examine how children learn novel words. It is not always apparent how much experience a child has with real words and this could be a possible confounding factor in language experiments. The use of novel words provides an unbiased approach since none of the subjects has had prior experience with the stimuli. When a child displays an N400 effect for pseudowords in the incongruent presentation, it shows that they have learned an association between this new object/word pair because they have reacted to the discrepancy. A low N400 component in the congruent presentation means the same thing; the child has accepted the semantic association and therefore does not react because the pretend object was called by the right name.

An example of this can be seen in an early cross-modal study with 14 month olds by Molfese, Morse and Peters (1990). It included a training phase for learning the names of four novel objects. Afterwards they tested the children to see if an association had been made. According to the data they found that there were distinct differences in EEG waveforms when the children saw pictures of objects paired with the right name or the wrong name. They were able to conclude that the children did indeed learn what the new objects were called since the incongruent presentations elicited an N400 response (i.e. the children reacted to the picture being called by the wrong name).

Hemispheric differences of the N400

Although the N400 is slightly larger in amplitude in the right hemisphere for adults, Friedrich and Friederici (2004) found that there was a difference between adults and children when they investigated N400 effects for semantic incongruity. Although not statistically significant, they saw that the incongruity effect in children in general is a bit stronger in the left hemisphere compared to adults. Furthermore, they could discern that hemispheric distribution was related to the amount of receptive vocabulary a child had. Children with low comprehension skills showed a smaller incongruity effect, which was stronger over the left hemisphere and peaked much later than for adults, while children with a large receptive vocabulary had a right hemisphere distribution and a peak that was similar to adults.

Torkildsen et al. (2006) found similar hemispheric differences. In their study, the 20 month old children with a high productive vocabulary had a stronger N400 that peaked around the same time as adults and occurred over the right hemisphere. The incongruity response of the low productive vocabulary group was smaller with a later peak and lateralized to the left hemisphere. They offered a possible explanation for this disparity by reasoning that the ability to recognize objects quickly and efficiently becomes greater as child's lexicon grows, and there is a processing shift to the right hemisphere. For very young children, matching pictures with words requires a lot of effort, especially for those with small vocabularies.

Semantic categorization and conceptualization

In order to explore what goes on in the early stages of language development, one must first try to understand how children categorize and ascribe meaning to things. There is a point of contention regarding the distinction between categorizing things using perceptual features (like color, size and shape) or conceptual attributes (what function an object has). Are they separate yet parallel processes or are they integrated?

Jean Mandler (2003) regarded the formation of perceptual categories as automatic and concrete while conceptual categorization involves more effort and is abstract. The two are therefore separate and independent but develop side by side.

David Rakison (2003) on the other hand believes that children learn representations for things through a continual and cumulative process and that “the information that underlies the developing concepts of infants and children is fundamentally perceptual in nature” (p. 161). Thus, there are not two systems for categorization; rather the conceptual representations evolve continuously during our lifespan out of perceptual representations.

Even though there are varying perspectives, one thing is certain- children become increasingly adept at developing categories through the incorporation of knowledge about contextual and perceptual features such as the presence of fur, how something is used or if it is animate or inanimate.

There are also two approaches in the research involving the creation of global and basic-level categories. One viewpoint maintains that the child learns a word for something which is then associated with a category and that helps to build up a concept. In this case the child is taught the word ‘ball’ and then begins to understand that balls are round since they have a similar shape (Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002).

It appears that young children categorize differently than adults and it has been thought that basic-level semantic categories are the first and easiest types of conceptual concepts children learn and make. Superordinate categories are deemed to be more difficult and are formed later (Rosch, Mervis, Gray, Johnson & Boyes-Braem, 1976). In other words, once the child learns the basic-level concepts of cars, motorcycles, trains and trucks, it is then possible to construct the superordinate category of vehicles. Gopnik and Meltzoff (1987) concluded that children begin to conceptualize what things are when they understand that you can sort objects into basic-level categories. They can then proceed to learn the names for these objects which results in a faster rate of word learning. It is also the interaction with an object that gives meaning to our basic-level categories because they are dependent on our perception, image and knowledge of the object (Tanaka & Taylor, 1991).

In contrast to the above position, more recent literature (e.g. Mandler, 2000; Quinn, 2003; Rakison, 2003) suggests that infants comprehend global categories or concepts first and in the second year, a refinement process begins enabling them to form basic level categories.

Rakison and Butterworth (1998) were interested to know if children under two could form superordinate categories by focusing on salient object details such as vehicle wheels or legs of animals. Results showed that the children were able to discern between animal and vehicle superordinate categories when they were in their unadulterated forms but were unable to discriminate between vehicles and animals when the exemplars were altered so they had the same parts (cars with legs and cows with legs or cars with wheels and cows with wheels). 14 and 18 month olds preferred to focus on a prominent detail to categorize objects even when it was possible to use the whole picture to determine category membership, whereas 22 month olds were able to use other cues and not attend solely to details to make categorical distinctions. This conclusion is important because it suggests that there is a developmental shift in perception during language acquisition in the second year.

Another aspect of categorization involves the ability to associate auditory information with visual stimuli (called *cross-modal processing*), which is critical for the comprehension and recognition of words. A further dimension to cross-modal processing includes having knowledge of the relationship between a word and its referent, which is of itself arbitrary and requires experience to correctly identify. This is maybe why very young children often have trouble calling things by the right name (Molfese et al., 1990).

Overextension

It has been well documented that infants often overextend words in the same superordinate category, for example, calling an apple a peach. Because so little is known about early language processing, it is not easy to work out whether an overextension is just a simple mistake, the result of having a broad concept for “fruit” or if the child believes an apple is the same thing as a peach.

Mandler (2004) thought that children form categories on a “global level”, meaning that they create superordinate-like categories that do not incorporate the basic level concepts into them. Overextension arises because concepts of common words are too broad.

Torkildsen et al. (2006) concluded however, that overextension results from “production obstacles rather than oversized conceptual categories” (p. 451), and that by 20 months (or even earlier), children can make a distinction between basic-level words in the same superordinate category. In other words they understand you can’t call a ‘horse’ a ‘dog’ even though they are similar in many ways.

Fast mapping

Fast mapping refers to the ability to rapidly gain information about a new object by process of elimination, evaluating it in context or comparing it to other familiar objects. Using this strategy, children can quickly infer the meaning of a new word even after only a few exposures to it. There are studies that suggest that children are actually able to fast map up to a half a year before the vocabulary spurt. Werker, Cohen, Lloyd, Casasola and Stager (1998) assert that their research on young children offers strong evidence that infants can quickly learn the arbitrary associations between objects and words and that it occurs around 14 months of age.

Fast mapping is not limited to object nouns but also includes words describing other features such as shape, texture and color. Heibeck and Markman (1987) found that shape was more important for understanding meaning than other attributes and that children who were taught shape words (for example square or round) gained more knowledge from them and retained them better than words for texture or color.

While there is no consensus in the research as to exactly why fast mapping occurs, various theories propose that children use fast mapping when they go from associative to referential learning (Gopnik & Meltzoff, 1987; Reznick & Goldfield, 1992) or that it is part of a more general learning process that develops over time and increases with experience (Regier, 2005). Carey and Bartlett (1978) who coined the term “fast mapping” believe it is associated with word learning but is a distinct and separate process. It also appears that fast mapping involves general cognitive abilities such as learning and memory and is not an innate mechanism of word learning in the brain (e.g. Alishali, Fazly & Stevenson, 2010; Regier, 2005). The more words a child knows, the easier it is to connect new words to novel objects with only a few presentations. This idea, called *leveraged learning* assumes that rapid vocabulary growth is a product of a gradual accumulation of words that gains momentum as the child’s lexicon increases (Mitchell & McMurray, 2009).

Cultural aspects of word learning

It can be argued that words are arbitrary since what we chose to call something does not have an inherent relationship with what it represents. This explains why the same object can have as many names as there are languages. A language is best understood in the context of the representations and symbols that are unique for a given culture. Language is also an integral part of the social environment in which it is learned and spoken. Social settings are important since they are often predictable and serve to help a child associate adult words with familiar objects, places or actions. Through repetition of these social interactions, the child can thus begin to understand the intentions of the people around them.

An interesting example of cultural differences in early language learning can be seen in the early vocabularies of English and Chinese children. Several researchers (e.g. Snedeker, Li & Yuan, 2003; Tardif, 1996) have compared the process of English and Mandarin word learning. They found that the early vocabulary of young English speakers consists mainly of nouns, while those learning Mandarin acquire more verbs. The cause of this is can be debated but one position maintains that nouns are more frequently used in English so it naturally follows that English speaking children will quickly acquire more nouns in their vocabularies. Early learners of Mandarin procure more verbs since they are a more prominent feature in Asian languages (Lee & Naigles, 2005).

Vocabulary Spurt

Since the most prolific area of language in the second year for western children is in the comprehension and production of nouns, the bulk of children’s vocabulary at this age is mostly made up of basic level labels for animals or things. Productive vocabulary refers to the words that a child can say; while receptive vocabulary includes all the words a child understands but may or may not be able to say. Young children have much larger comprehensive (receptive) vocabularies, especially before they go through a vocabulary spurt (Reznick & Goldfield, 1992).

As is the case with fast mapping, the literature is conflicted regarding the origin of the vocabulary spurt and which cognitive abilities are associated with it. Is there an actual “spurt” or does increased vocabulary reflect a child’s gradual intellectual processing and overall maturation? For quite a few children, the vocabulary spurt is also associated with a comprehension spurt that occurs around the same time (Reznick & Goldfield, 1992). It is thought that a child’s increased ability to categorize is linked to the vocabulary spurt but how they influence each other is unknown. It may be at this point however, that categories begin to reflect real meanings and true concepts (Quinn & Oates, 2004).

Much of the literature has theorized that as children begin to go through a vocabulary spurt it is an indication that the mechanisms that underlie learning have changed, although this has been challenged. An idea similar to leveraged learning has been put forth which reasons that learning itself may account for the rapid increase in word production during the second year and not changes in conceptual structures (Harris, 2004).

Most of the investigations examining productive vocabulary have used somewhat arbitrary markers as confirmation of the vocabulary spurt. There has been a general tendency to contend that if a child is a certain age and knows a certain number of words, then it would be safe to assume a spurt had taken place. Fenson et al. (1994) set the standard at a minimum of 50 words and asserted that 90% of children by age two will have productive vocabularies between 50-100 words, which indicates they experienced a spurt. Gopnik and Meltzoff (1987) had a requirement of 10 or more new nouns in a 3 week period. Lifter and Bloom (1989) believed a vocabulary spurt happened when a child had a minimum productive vocabulary of 20 words and learned at least 12 new words in a month (averaged at 3 new words in the same week). Although it seems easy to retrospectively conclude that children have experienced a vocabulary spurt, it could just as easily be due to a gradual improvement or other factors.

In fact, the notion that all children undergo one large spurt is probably erroneous since recent research shows that there is a wide variation in the learning curve for toddlers and that many children show continuous development while others may have several small spurts. Ganger and Brent (2004) re-examined the data from several prominent studies purporting to have found evidence for a vocabulary spurt. In order to identify the spurt, they looked for an inflection point, which is the transition point between a slow rate of word learning and an accelerated stage. Their results indicated that only around 20% of children actually experienced a spurt when analyzed in terms of an inflection paradigm. With this in mind, it is not a given that the vocabulary spurt in itself represents a universal cognitive transition but nonetheless the expanded knowledge of words in the second year is a significant milestone that is related to how children recognize and categorize objects.

The Shape Bias

Results from research on young infants show that they are able to create categories and that the naming of an object helps them focus on properties that are category relevant, although this takes place before a preference for shape develops. It has also been suggested that there might be a predisposition to attending to shape which is present but weak in infants and becomes stronger in the second year (Gershkoff-Stowe & Smith, 2004).

Most of the first 300 or so words that toddlers learn are in object categories organized by their shape. When a normally developing toddler hears the word for a novel object, there is a tendency to extend it to other objects that resemble it in shape. Selective attention to the dimension of shape is an interesting phenomenon called the *shape bias*. It is also thought that when children attend to shape in order to learn names for novel objects it may make learning easier (Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002). But what is the relationship between shape and learning nouns? Although the shape bias itself is not disputed, there is controversy concerning its prevalence, its connection to other cognitive abilities and its role in the processing of new information.

Keil (2008) highlights the disparity in approaches to understanding the shape bias and contends that is more likely a conflict regarding interpretation of the structures of basic cognitive development and learning. There are 2 prominent theories that try to explain why the shape bias emerges. The first is called the “attentional learning account”, which posits that the shape bias originates in a linguistic context because children learn associations between object categories and the names for objects.

Landau, Smith and Jones (1988) conducted early research on the significance of shape on infant’s learning. In their study with 2 and 3 year-olds, they found that in a classification task the children showed a distinct preference for shape as opposed to size or texture. They believe the shape bias is much more robust for word extensions and that the bias is language related and not just a part of general cognitive development.

Gerskhoff-Stowe and Smith (2004) explain it this way: every time a child learns the name for a new object that is categorized according to shape, it reinforces future attending to shape when new words are learned. Furthermore, when children focus on the shape of things, it makes it easier to learn new words for objects of a similar shape.

The other theory, termed “shape as cue” assumes that children understand that objects belong in categories and that shape is an important cue to categorization (e.g. Bloom, 2000; Gopnik & Meltzoff, 1987; Diesendruck, Markson & Bloom, 2003). The shape as cue proponents also believe that attention to shape is just one of many childhood developmental processes including perception and cognition.

These opposing viewpoints make a definitive explanation of the shape bias difficult, if not impossible to discern. The ‘real’ underlying cause may not be essential to know. Rather, the important thing is that there seems to be a relationship between vocabulary and attention to shape; children who know more words are better at recognizing objects based on shape, while those with limited vocabularies are better at recognizing objects based on prominent details.

ERP experiments and vocabulary

There have been some very promising ERP studies with young children that focus on the relationship between vocabulary size and word learning.

Friedrich and Friederici (2004) examined the relationship between vocabulary and word learning in meaningful contexts for 19 month old children. They wanted to explore the neural processes of semantic memory, which is the part of long term memory that has to do with ideas and concepts not related to personal experiences. Their study measured differences between children depending on their level of comprehensive (receptive) vocabulary and investigated N400 effects for semantic incongruity. 55 children were presented with pictures paired with their right names (congruent) or their wrong names (incongruent). The subjects were grouped post hoc into 2 categories: high comprehensive vocabulary and low comprehensive vocabulary. They found that children with limited comprehension (low group) showed just a small N400 effect whereas children in the high vocabulary group produced an effect that was much larger for semantic incongruity. For all children the incongruous presentations elicited a greater N400 than congruent ones. Another interesting find in this study is that all the children were able to access semantic knowledge before the whole word was even said.

A recent study by Torkildsen et al. (2009) centered on finding out which neural mechanisms are activated during receptive word familiarization in 20 month old children and the relationship to productive vocabulary. They employed a repetition task where associations between novel pictures/words were built up through a training phase and then violated in the test phase. Real pictures/words were used as a control measure. The subjects were divided into two vocabulary groups; low (<75 words) and high (>75 words). The results showed that N400 effects were clearly demonstrated by the high group for pseudowords whereas the low group showed no N400 for pseudowords but did for real words in the incongruent presentation. Furthermore, children with high productive vocabularies were able to learn the new words in just 3 repetitions compared to low producers who took 5 trials to learn them.

Mills, Plunkett, Prat and Schafer (2005) noted that previous research showed hemispheric differences during familiar and novel word processing in children during the second year. What began as bilateral shifted to the left hemisphere with an increase in productive vocabulary size. They wondered if this was due to the size of a child's vocabulary or the result of word familiarization. They conducted an ERP experiment using familiar and novel words with 20 month olds in order to test which explanation was more plausible. The subjects were divided into two groups (high or low productive vocabulary) and they found that both groups presented a bilateral distribution but that children in the high vocabulary group displayed a larger difference in the left hemisphere for newly acquired novel words. The findings suggest that word familiarity is a crucial factor when it comes to which brain regions are involved but that a combination of the two explanations is plausible. They believe that "quantitative factors, such as rate of acquisition and amount of exposure to individual words, may be adequate to account for dynamic shifts in ERP activity observed in children as they acquire their mental lexicon" (p. 30).

Purpose of this study

The present study is an offshoot of a larger project being conducted at Lunds Universitet. It has been designed to have a more limited focus, although with a similar purpose. The larger project is expected to last 3 years and has gained attention from the media, where it was featured in an article in a major newspaper as well as on their internet website. It includes a behavioral test as well as a follow-up test phase almost identical to the first experiment when the original children turn 24 months, in the hopes that the longitudinal information will shed even more light in this area.

The purpose of this study is to better understand young children's early categorization strategies and the role that shape plays in the recognition of novel objects and the brain mechanisms involved with novel word learning. An important dimension and focus of this study is the relationship between productive vocabulary size and the shape bias, which have been linked together in previous studies referred to in this paper. Since little has been written about the neural components of object recognition and lexical-semantic processing in children between 1-3 years, it is an area in need of research. In fact, there have been no other studies with toddlers that have examined the impact of productive vocabulary on the neural correlates of shape attendance, which is why the present study may prove to be a valuable contribution to this branch of research.

This study is similar to the ERP design employed by Torkildsen et al. (2009) in which they wanted to investigate the neural components involved when a child learns new words and whether this is related to the size of a child's productive vocabulary. In addition to this paradigm, conditions for the shape and details of objects are incorporated, which reflects interest in the behavioral research by Pereira and Smith (2009) who found that children with small productive vocabularies focused more on the salient details of objects in contrast to children with large productive vocabularies who paid attention to the shape of objects.

As Friedrich and Friederici (2005a) revealed in their study with pseudowords, children in the second year treat pseudowords as potential word candidates and that a decreased N400 component in the congruent presentations indicates that the children have learned associations between novel words and their corresponding pictures. Alternately, the presence of the N400 effect for incongruent presentations of pseudowords should signify that the participants have accepted and learned the pseudowords and have reacted to a semantic violation.

Since the majority of the participants in this study have what can be considered large vocabularies, it was not practical to divide them into 2 groups of high and low producers and instead, the subjects were kept as one group. We can speculate that almost all of the children have gone through something like a vocabulary spurt because of their vocabulary size, which means they should also show a preference to shape when learning new words.

We would expect the participants to display an N400 effect for incongruent presentations of real words in the silhouette condition since they should already be familiar with them. We would like to see however, if the children are able to do this with the pseudowords that they have just learned and if they are capable of recognizing them in the silhouette condition that represents shape. In regards to the role of vocabulary we can ask the question “can vocabulary size predict the amplitude of the N400”? Or, referring specifically to the relationship between productive vocabulary and the shape bias for children in the second year “does having a large productive vocabulary increase the amplitude of the N400 in the shape condition”?

On the basis of the body of literature that has been introduced in this paper, the following hypotheses are presented:

1. *An N400 effect will be seen for incongruent presentations of the experimental stimuli.*

2. *Children with large productive vocabularies will display an N400 effect for the incongruent presentations of real words in the silhouette condition.*

   Most importantly:
3. *Children with large productive vocabularies will display an N400 effect for the incongruent presentations of pseudowords in the silhouette condition.*

Method

Recruitment

In order to be eligible to participate in this study, the children had to be 20 months old and native Swedish speakers. The children used in this study were recruited with the help of local health and daycare centers in and around Malmö and Lund in Southern Sweden. Posters describing the study were set up in waiting rooms and school cloakrooms. Parents of eligible children interested in participating contacted the researchers and set up an appointment.

Participants

The participants recruited for this study consisted of 36 healthy, full-term normally developing children with Swedish as their native language. A few of the children had one parent who was not born in Sweden but Swedish was the spoken language in the household. Bilingual children were not included in the study.

22 children were excluded on the basis of incomplete trials (usually not being engaged in the task and/or having to stop before the experiment was over) or corrupted data due to too much movement or the child being upset. 14 subjects met the criteria for being included in the experiment (finishing at least 10 out of 30 trials in each condition) and out of these there were 8 girls and 6 boys, ranging in age from 20 months plus or minus 2 weeks. All children who participated in the experiments received a T-shirt.

Consent and Materials

Parents who responded to the advertisements were given a test appointment and sent a package containing The Swedish Early Communicative Development Inventory (SECDI) (Eriksson & Berglund, 2002), which is the official Swedish version of the MacArthur-Bates Communicative Inventories (MCDI) (Fenson et al., 1994), as well as the Swedish version of the Ages and Stages Questionnaires (ASQ) adapted from the Norwegian version (Janson & Smith, 2003). The ASQ is a generalized developmental screening tool with a special form for 20 month olds. The parents were also asked to sign a consent form and give information about their educational level and profession. This material was completed at home and brought on the day of testing. Parents also received a verbal explanation of the testing procedures and practicalities right before the experiment.

The SECDI is designed to assess language and communication skills in young children and consists of two parts. The first is Words and Gestures (infant form), which is for children up to 16 months and used in this study with the 20 month olds. The second part is Words and Sentences (toddler form) which is aimed at children 16-30 months.

The SECDI was utilized in order to obtain the size of each participant's productive and comprehensive vocabulary and it was scored by hand according to instructions in the manual. The children thus obtained 2 separate scores for productive vocabulary that was later averaged into one mean score.

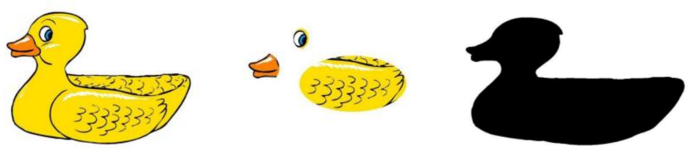
Computer presentations

The software E-Prime 2.0 Professional (Schneider, Eschman & Zuccolotto, 2002) was used for the computer presentations and included a total of 60 pictures paired with corresponding names. Half of the pictures were of animals and the other half were objects. In addition, half of the pictures were of real animals or things and the other half were of pretend animals or objects. In other words there were pictures of 15 real animals plus 15 real objects, and there were pictures of 15 pretend animals plus 15 pretend objects. The real animals and objects were taken from items in the SECDI. The pretend pictures were found on the website clipart.com (See *figure 1.).*

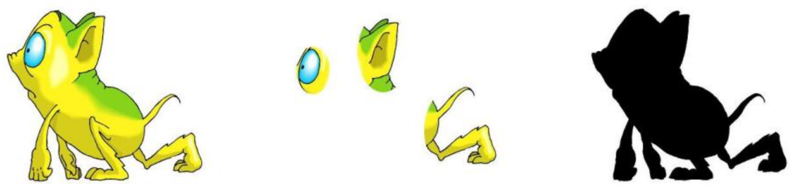
Figure 1.

Examples of whole pictures, details (salient parts) and silhouettes

1a. real animal: “anka”

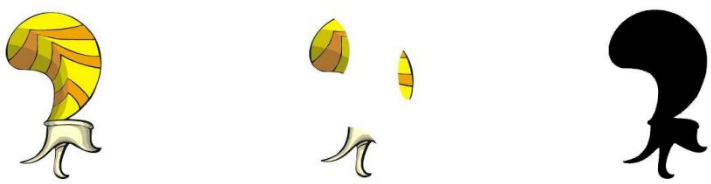


1b. pretend animal: “minge”



1c. real object: “bil”

1d. pretend object: “vir”



The experiment’s audio component was conducted in a sound attenuated chamber and contained a recording of a female voice saying 30 real Swedish words and 30 pseudowords that were phonotactically legal and had one to three syllables.

ERP recording

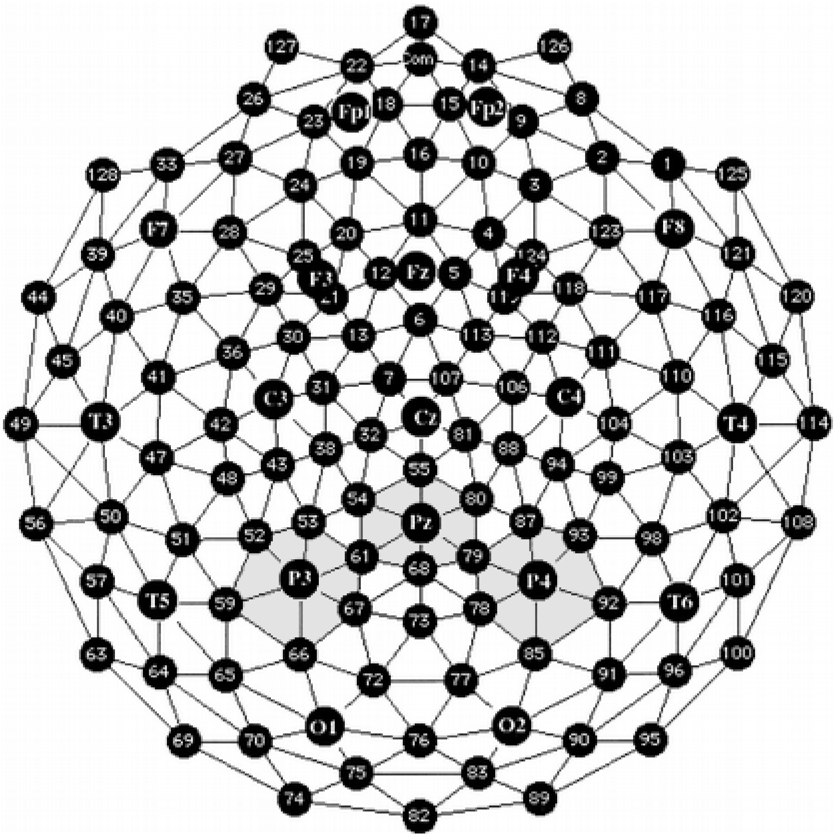
A NetAmps 300 amplifier with a sampling frequency of 250 per second was used along with Netstation 4.3.1 software for recording and analyzing the data. In accordance with the manufacturer's guidelines, impedance was kept below 50 Ω. A smaller HydroCel Geodesic Sensor Net (HCGSN) with 128 channels designed especially for children was used to register standard ERP recordings during the experiment. Four electrodes were deactivated (125-128) as well as the forehead electrode (17) due to the fact that these were bothersome for the children. The electrodes were referenced during the recording to CZ. A video camera was placed near the computer monitor to record the child's actions during the experiment. Both the video and the corresponding EEG data were synchronized and saved.

Figure 2.

Picture of a young child wearing the HydroCel Geodesic Sensor Net;

Figure 3.

Picture of a geodesic sensor net. In this study P3, Pz and P4 are the main areas of interest.



Data Analysis

The data was then put through a 1-30 Hz band pass filter to reduce the amount of ‘noise’ and divided into 15 categories depending on what the stimulus was (for example the incongruent silhouette presentation for real words, or the congruent presentation of the whole picture for pseudowords). Then it was made into segments in which each segment of the EEG was 1.1 seconds in total, beginning at 100 ms before the word onset and lasting 1000 ms. The segments were run through an automatic artifact detection program that screened for bad channels (defined as fluctuations in the ERP wave over 150 µV during a segment) and bad segments (more than 15 bad channels per segment).

The data was manually scanned for inattention by watching the video and looking at the EEG topography. Every time a child looked away from the computer screen the video was stopped and the affected segment was closely screened to see if they had missed seeing the picture or the picture/word pairing. The criteria used for declaring a bad segment and taking it out of the overall analysis were:

1. if the child was inattentive at the stimulus onset then the word or picture was removed.

2. if the child was inattentive during the final 800 ms of the preceding picture then the word was removed.

3. if the child was not attentive for at least 700 ms after stimulus onset then the word or picture was removed.

4. if there was a visible movement artifact within 1000 ms after the stimulus.

Procedure

Participants sat in their mother or father’s lap during the experiment with a 17 inch computer screen approximately 35 cm. in front of them. They were filmed during the whole ERP experiment, which lasted approximately 45 minutes including the measuring and fitting of the Geodesic Sensor Net. Pictures were shown on the computer screen for a total of 2150 ms with the auditory component (spoken word) starting 1000 ms after the picture onset. In between presentations there was a white screen that remained visible for 500 ms. The ERP paradigm consisted of a learning phase and a test phase. The pictures were introduced in 10 blocks and each block was 3 minutes long. During the learning phase there were 30 presentations in each block which were made up of 3 pictures of real things plus the corresponding words and 3 pictures of pretend things with corresponding pseudowords. The real pictures however, were always paired with a real word and the pretend pictures were always paired with a pseudoword. Each picture/ word combination was shown 5 times (5 trials in total).

The last part of each block was the test phase, which consisted of 30 presentations and was carried out by showing the pictures from the learning phase at random, paired with an incorrect word from the same block. Like in the learning phase, the real pictures were always paired with a (wrong) real word and the pretend pictures were always paired with a (wrong) pseudoword. The same picture was never shown twice in a row. In addition to whole pictures, the objects were also displayed as silhouettes or detail clusters. The silhouette version was similar to a black shadow and the detail version was expressed as a cluster of 3 prominent features (see figure 1). The silhouette and the detail versions were paired once with the correct (congruent) word and once with the incorrect (incongruent) word.

Sometimes the subjects needed to take a short break which was done in between trials. Raisins and cookies were given to encourage further participation if a child was getting tired or losing concentration. If a child was in obvious distress (crying or fussing), the experiment was immediately stopped. Sometimes the child was able to resume, other times not.

Vocabulary scores

The vocabulary scores from the SECDI consisted of a comprehensive (receptive) score, which is the parent's assessment of what their child understands but may or may not be able to say, and a productive score, which is what words the child can say. The productive scores were obtained from the SECDI for younger children (up to 16 months) as well as the SECDI for children between 16-30 months. The use of the 16 month SECDI was mostly a control measure since many of the words on both instruments are the same. Of course, a wide variation can be seen between the subjects' scores, which can be thought of as a reflection of younger children's development in general. The productive vocabulary scores on the SECDI for <16 months had a minimum of 9 words and a maximum of 299 words (SD = 95.6). The average for all 14 participants was 114 words. On the SECDI for 16-30 months, the scores ranged from 12 to 514 (SD = 150.6) and a mean of 154 words. The two productive vocabulary scores combined and averaged ranged between 12 and 407 words (SD = 122.3) and had a mean of 134 words.

Statistical analyses

The data was analyzed by dividing it into four consecutive time windows; 400-500 ms., 500-600 ms., 600-700 ms. and 700-800 ms. To investigate whether the subjects would attend to shape during novel word learning, a four way repeated measures analysis of variance (ANOVA) was performed in each time interval with *word type* (pseudowords and real words), *condition* (whole pictures, details and silhouettes), *congruence* (incongruent and congruent) and *region* (parietal left [P3], parietal central [Pz] and parietal right [P4]) as within-subjects factors. The parietal electrode sites were chosen because this area of brain has been documented to capture the best ERP effects for studies with children comparing known words and pseudowords.

Regression analyses were performed to investigate the effect of vocabulary size on novel word learning. The 600-700 ms. time window yielded the most interesting results. To get a better response in the regression analyses for region, the factor for electrode site was averaged into one value creating an aggregated score of all three parietal areas. The first regression analysis was done to test the hypothesis that the subjects would display an N400 effect for real words in the silhouette condition for incongruent presentations since they had a high vocabulary and were already familiar with the real words. Vocabulary size was the predictor variable.

The second regression analysis was conducted using the data from the 600-700 ms. time window in order to test if productive vocabulary could predict the size of the N400 amplitudes. This time the congruence variable was converted by subtracting the congruent values from the incongruent values, giving one measurement (in other words this measurement is the difference between the two levels). Vocabulary size was the predictor variable.

Results

ANOVA results

In the 400-500 time window there was a significant main effect only for *word type* [$F(1,13) = 7.06$, $p = .020$] which means that there was a difference between pseudoword and real word presentations. The 500-600 time window showed no significant interactions or effects, [$F(1,13) = 2.02$, $p > .05$] (all other values were larger). In the 600-700 window there was a significant main effect for *congruence* [$F(1,13) = 8.19$, $p = .013$] and as is normally the case, the incongruent level had higher amplitudes. There was a significant main effect for *region* [$F(2,26) = 5.54$, $p = .010$] as well as a significant interaction between *congruence* and *region* [$F(2,26) = 5.26$, $p = .012$]. The latter finding reveals that the three parietal areas are stimulated differently during congruent and incongruent presentations. Additionally, there was an almost significant main effect for *condition* [$F(2,26) = 3.24$, $p = .055$]. In the last time window, 700-800 there was a significant main effect only for *region* [$F(2,26) = 9.77$, $p = .001$].

Regression Analyses

As a control measure, a regression analysis was conducted to test the hypothesis that the subjects would react when real words were called by the wrong name in the presentation for shape. Confirming our expectations, the results of this analysis showed a significant N400 effect for incongruent presentations of real words in the silhouette condition, $\beta = -0.64$, $t(12) = -2.88$, $p = .014$. $R^2 = .40$, $F(1,12) = 8.28$, $p = .014$.

Results of the second regression analysis show a significant effect for the pseudowords in the silhouette condition, which means that children with larger vocabularies also had larger N400 amplitudes in the silhouette presentation, $\beta = .56$, $t(12) = 2.33$, $p < .05$. $R^2 = .31$, $F(1,12) = 5.42$, $p < .05$. This result validates the supposition that 20 month old children with large productive vocabularies would be sensitive to shape when learning novel objects/words.

Discussion

The results of the analyses conducted in this study provide a statistical basis on which to answer the questions that were posed earlier in this paper, namely; Do the 20 month old children in this study show a preference to shape as a way to recognize known words, and can productive vocabulary size predict whether a child exhibits a sensitivity to shape when learning novel words?

Hypothesis 1:

The ANOVA results present significant main effects for congruence (congruent, incongruent) and region (3 parietal areas) and an almost significant main effect for condition (whole picture, details or silhouette). As was expected, the amplitudes for the incongruent presentations (pictures paired with the wrong name) that represent semantic violation were larger, thus enabling a confirmation of the first hypothesis.

Because the incongruent presentations elicited a larger N400 response than those that were congruent, we can surmise that the subjects learned the associations between words and their referents and subsequently responded when these associations were broken.

The significant main effect for *region* revealed that the experimental conditions (word type, the 3 types of presentations and congruence) exerted a varying impact on the parietal electrodes. The significant interaction between *congruence* and *region* reveals that incongruent presentations affect the parietal areas in different ways but a more in-depth analysis of exactly which regions were stimulated by each of the conditions is beyond the scope of this paper.

Hypothesis 2:

The regression analyses were conducted to see whether an association could be found between vocabulary size and the magnitude of the N400 amplitudes in the silhouette condition that represents shape. It was predicted that the children would display an N400 effect for real words in silhouette form which is exactly what we see from the results of the first regression. Although this is used as a control measure, the presence of an N400 effect means that the necessary neural mechanisms were in place so that the children could recognize associations between real words and their referents even in the more advanced shape condition. Additionally, this result provides a basis on which to postulate the second hypothesis in this study regarding the learning of pseudowords.

The finding from the first regression is in line with Torkildsen et al. (2009), who found in their ERP study that 20 month old children in both high and low vocabulary groups reacted to incongruous presentations for real words (although they did not assess the role of shape), which demonstrates an ability to process and recognize the experimental stimuli. Vocabulary size did not seem to make a difference in this ability since both the low and high groups were able to recognize the real pictures. The addition of a shape condition in this experiment however, makes vocabulary size an important component which is why a regression analysis was conducted with the vocabulary size as the predictive factor.

The real words used in this experiment were taken from the SECDI, making it probable that most of our participants would be acquainted with them. Since the average vocabulary size of the group of children was high, it was also likely that they would show a sensitivity to the condition for shape (silhouette). The significant result for the silhouette condition validates the hypothesis that children with a high productive vocabulary would attend to shape during word recognition. The mean size of productive vocabulary for the participants in this study can account for the results regarding the N400 responses to incongruity in the silhouette condition. Since all of the subjects were the same age, it was the individual vocabulary levels that set them apart. While there were children in the group with much less vocabulary than the mean (there were four children with productive vocabulary scores under 50), the group as a whole are high producers (M=134) making it likely that most of the participants in this study have experienced a vocabulary spurt and were more apt to categorize new objects by what shape they have rather than focusing on specific details.

Pereira and Smith (2009) have stated that age and vocabulary size are for the most part positively correlated, but recognition of the shape caricatures indicates a much more robust relationship to vocabulary size than age. They postulate further that “category knowledge as measured by productive vocabulary appears to be specifically related to the formation of sparse representations of global shape” (76). The results of the present study seem to concur with this statement which is apparent in the significant effects found in the silhouette condition.

Hypothesis 3:

The results of the second regression analysis indicate that the participants were able to establish meaningful associations between the novel pictures and pseudowords since they reacted with an N400 effect when an association was broken in the silhouette (shape) condition. In other words, children with large productive vocabularies showed a sensitivity to shape when learning the associations between novel picture/word pairs.

This result is interesting because it shows that it is in the separation of the congruence variable, or the difference between the two, that we find a meaningful connection. This does not arise in the first regression analysis where the congruency parameter was not converted. This result also confirms that there was indeed a difference between the congruent and incongruent presentations because as it was speculated, the incongruent presentations elicited larger N400 amplitudes.

Although there are no other studies that explicitly explore the relationship between the neural mechanisms of productive vocabulary and shape attendance in language acquisition for children in the second year, the findings in this paper are in accordance with previous research on both the shape bias and the influence of vocabulary on novel word learning (e.g. Pereira & Smith, 2009; Torkildsen et al., 2009; Friedrich & Friederici, 2010).

That there was a significant effect for pseudowords in the silhouette condition attests to a higher language processing. As presented earlier in this paper, attending to shape when forming an association between a pseudoword and its referent is considered a more advanced process which occurs once children have acquired a larger vocabulary (50-150 words) and are between 18-30 months old (Gerskoff-Stowe & Smith, 2004). It also appears that vocabulary size is more important than age when it comes to word processing capabilities in toddlers. This can be seen in the wide (normal) variability of this age group and reflects the maturing of brain systems that are relevant to language acquisition (Mills, Coffey-Corina & Neville, 1993; 1997).

One thing that was not examined in this study was the effect of familiarization. This refers to repeatedly showing the paired stimuli several or more times and is a type of semantic priming. The learning phase in this experiment consisted of five trials in order to get the subjects familiar with both real and pseudowords and their referents. It is unknown if the number of trials played a part in the results from the subsequent test phase. We can speculate from the second regression results that five trials were adequate but maybe it would have taken even less trials to produce the same results, or that the results would have been different altogether with less learning trials.

Torkildsen et al. (2009) observed a difference between vocabulary size and how many trials it took for the subjects in their study to distinguish the novel words and referents in the test phase. High vocabulary groups only needed three trials to learn the associations. They also noted a difference between the processing of real and pseudowords which was contingent on vocabulary size. They concluded that only the high production group was helped by repetition for pseudowords as demonstrated by N400 effects to semantic incongruity in the novel word condition, but also that the "findings from the test phase accord well with the presence of the N200–400 familiarization effect for both novel and real words in the high production group" (p. 83).

Torkildsen (2008) advises caution however, when drawing conclusions about the positive correlation between vocabulary size and N400 amplitudes in toddlers because in adults and older children, the N400 amplitudes decline with age. She states that "it is possible that the observed pattern is due to a relation between vocabulary and the *presence* of the N400 rather than the absolute amplitude of the component (p. 64). If this is the case then more research needs to be done to demonstrate a relationship not based specifically on N400 amplitude size.

Conclusion

This study was conducted to explore the neural processes that occur when children learn new words. It may be seen as a first step in trying to map out the neural mechanisms involved with early word learning and the role that shape plays in this process. Since this is a relatively recent area of interest, there are still many gaps left to fill in the research. The motivation for this study lies in the fact that there have been no other ERP studies looking specifically at the shape bias and its relationship to language production in young children, something that makes this paper a unique contribution to the research community. It can however be difficult to translate theoretical concepts into experimental paradigms that can shed light on the phenomenon under investigation, especially when it comes to young children.

Limitations of this study

The use of EPRs to study neurolinguistic aspects of early childhood development has proven to be a suitable technique but there also limitations. Discovering ERP components that truly reflect the neural processes of linguistic phenomena is tricky and requires many new studies to establish reliable waveform correlations. One of the most obvious limitations of using ERP measurement techniques with children is that of cooperation. Many, if not most children think that it’s scary or uncomfortable (at least initially) to wear the electrode cap. This can result in the child protesting or crying as it is placed on the head. The cap allows only limited movement once hooked up to the computer which can feel restrictive to toddlers. The cap is also wet due to the solution to enhance electrical conductivity and sometimes drips into their faces causing distress. Luckily, many children forget about the cap for periods of time once they start looking at the stimuli.

Another major limitation working with young children is the fact that their concentration levels are low and they lose interest quickly. It is hard for a two year old to sit still for 30 minutes looking at a computer screen, even with small breaks in between. Artifacts due to head or eye movement can be a big problem and requires software and/or manual detection to reduce it.

Many of the children in this study became sleepy in the dark room with the repetitive voice in the background. It is unknown how this affected the results, but can be seen as par for the course when working with children in this age group. Because of the reasons just described, there were only 14 subjects out of 36 who completed enough clean trials to be included in this experiment, so many more children need to be recruited in these types of studies compared to those with adults. It is possible that because of the inherent challenges of working with very young children, many researchers choose another age group or area of interest. Maybe this somewhat accounts for the rather limited amount of electrophysiological studies with one to three year olds.

Although the SECDI, which is used to measure lexical development in children, is a statistically sound instrument, the use of parent questionnaires is not always reliable. There may be overestimation or underestimation about the child's abilities and it is a somewhat subjective appraisal. This might affect results of language studies with young children especially if the parent has overestimated how much receptive or productive vocabulary their child has. It is also difficult to establish how much experience a child has had with certain words. Some may have only used it once, others many times but this is not evaluated for in the questionnaires. It can be even more complicated for a parent to estimate which words the child understands (receptive vocabulary) especially if they cannot say them. Fenson et al. (1994) however, address some of these issues and how they affect the validity and reliability of the parent report measure and the MacArthur-Bates Communicative Development Inventories (of which the SEDCI is a translated Swedish version) is the most widely used instrument of its kind and has been used for over 20 years to assess a children's language development.

Another thing to consider is that the majority of the subjects in this study come from Lund, which is a small town with a large university as well as several large technological research centers. Almost all of the parents of the children are college educated & it is possible that having an academic background made these parents sympathetic to the benefits of research and added to the likelihood of letting their children participate in the experiments. In addition, these children might possibly have an advantage when it comes to learning language because they may be exposed to a more varied and extensive linguistic environment especially if their parents regularly read to them. It would therefore be interesting to replicate this study with children from more diverse backgrounds to see how the results compare, although the practicalities of recruitment from other socio-economic backgrounds and the number of subjects necessary for being able to generalize the findings make this a challenge.

Implications for future research

Besides contributing to the basic knowledge of the neural mechanisms responsible for infant lexical processing, the present study could be useful in conjunction with other similar studies, to help establish a baseline for what is considered "normal" language development in the second year, thus facilitating research with children who have specific language impairments (SLIs) or dyslexia.

Dyslexia is one of the most common neurological disorders in children and it not only affects how a child does in school but socially and emotionally as well. It is thus crucial to be able to see who is at risk early on. The earlier this disorder can be identified in a child, the earlier interventions can be employed, making for a better overall prognosis.

Researchers have become interested in studying younger at risk children before they learn to read in school because “they have not yet been affected by the results of compensatory mechanisms and less reading experience than other children” (Torkildsen, 2008, p. 31). It is also important to be able to separate the causes of dyslexia from the effects the disorder has on the child, which can be very different.

There have already been some ERP studies that have contributed to mapping out neurological differences in language processing for young children at risk for dyslexia by comparing them to control groups like the one in the present study. Torkildsen, Syversen, Simonsen, Moen, and Lindgren (2007b) found that the 20 month olds at risk for dyslexia did not display an N400 incongruity effect at all. The N400 could be observed in 24 month old at risk children, but with a much later peak and a left hemispherical distribution. Thus, a big difference can be seen between at risk and normally developing children.

Friedrich and Friederici (2006) tested young children at 19 months and again at 30 months to find out if a delayed lexical semantic development at 30 months for at risk children could already be seen at 19 months. They divided the subjects into two groups- those with age- adequate expressive language skills or those with poor expressive language skills. They found that poor skills at 30 months were indeed associated with language difficulties a year earlier and that 19 month old at risk children were “already delayed in the maturation of semantic integration mechanisms indexed by the N400” (p. 9).

It will no doubt take many additional ERP studies to understand more about the processes involved in word learning and the neural mechanisms underlying language acquisition in young children. There are still many unanswered questions, which highlights the need to further explore this area for both theoretical implications as well as clinical applications.

References

Alishahi, A., Fazly, A., Stevenson, S. (2010). *Fast mapping in word learning: What probabilities tell us.* Paper presented at the 12th Conference on Computational National Language Learning (CoNLL), Toronto, Canada.

Bloom, P. (2000). *How children learn the meanings of words.* Cambridge, MA: MIT Press.

Carey, S., & Bartlett, E. (1978). Acquiring a single new word. *Papers and Reports on Child Language Development, 15*(1), 17-29.

Eriksson, M., & Berglund, E. (2002). *Instruments, scoring manual and percentile levels of the Swedish Early Communicative Development Inventory, SECDI* (FoU-rapport 17). Gävle, Sweden: Institution for pedagogik, didaktik och psykologi.

Fenson, L., Dale, P.S., Reznick , J. S., Bates, E., Thal, D. J., Pethick, S. J., Tomasello, M., Mervis, C. B., & Stiles, J. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development, 59*(5), v-185.

Friedrich, M., & Friederici, A. D. (2004). N400-like semantic incongruity effect in 19 month olds: Processing known words in picture contexts. *Journal of Cognitive Neuroscience, 16*(8), 1465-1477.

Friedrich, M., & Friederici, A. D. (2005a). Lexical priming and semantic integration reflected in the event-related potential of 14 month olds. *Neuroreport, 16*(6), 653-656.

Friedrich, M., & Friederici, A. D. (2005b). Phonotactic knowledge and lexical-semantic processing in one year olds: Brain responses to words and nonsense words in picture contexts. *Journal of Cognitive Neuroscience, 17*(11), 1785-1802.

Friedrich, M., & Friederici, A. D. (2008). Neurophysiological correlates of online word learning in 14-month-old infants. *Neuroreport*, *19*(18), 1757-1761.

Friedrich, M., & Friederici, A. D. (2010). Maturing brain mechanisms and developing behavioral language skills. *Brain and Language*, *114*(2), 66-71.

Ganger, J., & Brent, M. R. (2004). Re-examining the vocabulary spurt. *Developmental Psychology, 40*(4), 621-632.

Gershkoff-Stowe, L., & Smith, L. B. (2004). Shape and the first hundred nouns. *Child Development, 75*(4), 1098-1114.

Gopnik, A., & Meltzoff, A. (1987).The Development of categorization in the second year and its relation to other cognitive and linguistic developments. *Child Development, 58*(6), 1523-1531.

Harris, M. (2004). First Words. In J. Oates & A. Grayson (Eds.), *Cognitive and Language Development in Children* (pp. 61-112). Oxford: Blackwell Publishing Ltd.

Heibeck, T. H., & Markman, E. M. (1987). Word learning in children: An examination of fast mapping. *Child Development, 58*(4), 1021-1034.

Hillyard, S. A., & Kutas, M. (1983). Electrophysiology of cognitive processing. *Annual Review of Psychology, 34*(1), 33-61.

Janson, H., & Smith, L. (2003). *Norsk manualsupplement til Ages and Stages Questionnaires.* Oslo: Regionsenheter for barn och unges psykiske helse, Helseregion Øst/Sør.

Jones, S. S., Smith, L. B., & Landau, B. (1991). Object properties and knowledge in early lexical learning. *Child Development, 62*(3), 499-516.

Kiel, F. C. (2008). The shape of things to come: The future of the shape bias controversy. *Developmental Science, 11*(2), 216-222.

Kutas, M., & Federmeier, K. D., (2000). Electrophysiology reveals semantic memory use in language comprehension. *Trends in Cognitive Sciences, 4*(12), 463-470.

Landau, B., Smith, L. B. & Jones, S. S. (1988). The importance of shape in early lexical learning. *Cognitive Development, 3*(3), 299-321.

Lee, J., & Naigles, L.R. (2005). The input to verb learning in Mandarin Chinese: A role for syntactic bootstrapping. *Developmental Psychology, 41*(3), 529-540.

Lifter, K., & Bloom, L. (1989). Object knowledge and the emergence of language. *Infant Behavior and Development, 12*(4), 395-423.

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

Mandler, J. (2000). Perceptual and conceptual processes in infancy. *Journal of Cognition and Development, 1*(1), p. 3-36.

Mandler, J. (2003). Conceptual categorization. In D.H. Rakison, & L.M. Oakes, (Eds.), *Early category and concept development. Making sense of the blooming, buzzing confusion* (pp.103-131). Oxford: Oxford University Press.

Mandler, J. (2004). Thought before language. *Trends in Cognitive Sciences, 8*(11), 508-513.

Markson, L., Diesendruck, G., & Bloom, P. (2008). The shape of thought. *Developmental Science, 11*(2), 204-208.

Mills, D. L., Coffey-Corina, S. A., & Neville, H. J. (1993). Language acquisition and cerebral specialization in 20- month- old infants. *Journal of Cognitive Neuroscience, 5*(3), 317-334.

Mills, D. L., Coffey-Corina, S. A., & Neville, H. J. (1997). Language comprehension and cerebral specialization from 13 to 20 months. *Developmental Neuropsychology 13*(3), 397- 445.

Mills, D. L., Plunkett, K., Prat, C., & Schafer, G. (2005). Watching the infant brain learn words: Effects of vocabulary size and experience. *Cognitive Development, 20*(1), 19-31.

Mitchell, C., & McMurray, B. (2009). On leveraged learning in lexical acquisition and its relationship to acceleration. *Cognitive Science, 33*(8), 1503-1523.

Molfese, D. L., & Molfese, V. J. (1997). Predicting language performance at 5 years of age from evoked potentials recorded at birth. *International Journal of Psychophysiology, 25*(1), 18-19.

Molfese, D. L., Morse, P. A., & Peters, C. J. (1990). Auditory evoked responses to names for different objects: Cross-modal processing as a basis for infant language acquisition. *Developmental Psychology, 26*(5), 780- 795.

Pereira, A. F., & Smith, L. B. (2009). Developmental changes in visual object recognition between 18 and 24 months of age. *Developmental Science, 12*(1), 67-80.

Quinn, J. (2003). Concepts are not just for objects: Categorization of spatial relation Information by infants. In D.H. Rakison, & L.M. Oakes, (Eds.), *Early category and concept development. Making sense of the blooming, buzzing confusion* (pp. 50-76). Oxford: Oxford University Press.

Quinn, J., & Oates, A. (2004). Early category representation and concepts. In J. Oates & A. Grayson (Eds.), *Cognitive and Language Development in Children* (pp. 21-60). Oxford: Blackwell Publishing Ltd.

Rakison, D.H. (2003). Parts, motion and the development of the animate-inanimate distinction in infancy. In D. H. Rakison & L. M. Oakes (Eds.), *Early category and concept development. Making sense of the blooming, buzzing confusion* (pp. 159-192). Oxford: Oxford University Press.

Rakison, D.H., & Butterworth, G. E. (1998). Infants' use of object parts in early categorization. *Developmental Psychology, 34*(1), 49-62.

Regier, T. (2005). The Emergence of Words: Attentional Learning in Form and Meaning. *Cognitive Science, 29*(6), 819-865.

Reznick, J. S., & Goldfield, B. A. (1992). Rapid change in lexical development in comprehension and production. *Developmental Psychology, 28*(3), 406-413.

Rosch, E., Mervis, C. B., Gray, W. D., Johnson, D. M., & Boyes-Braem, P. (1976). Basic objects in natural categories. *Cognitive Psychology, 8*(3), 382-439.

Schneider, W., Eschman, A., & Zuccolotto, A. (2002). *E-Prime User´s Guide.* Pittsburgh, PA: Psychology Software Tools Inc.

Smith, L. B., Jones, S. S., Landau, B., Gershkoff-Stowe, L., & Samuelson, L. (2002). Object name learning provides on-the-job training for attention. *Psychological Science, 13*(1), 13-19.

Snedeker, J., Li, P., & Yuan, S. (2003). Cross-cultural differences in the input to early word learning. In R. Alterman & D. Kirsh (Eds), *Proceedings of the Twenty-fifth Annual Conference of the Cognitive Science Society*, (pp. 1094–1099). NJ: Lawrence Erlbaum Associates.

Tanaka, J.W., & Taylor, M. (1991). Object Categories and Expertise: Is the basic level in the eye of the beholder? *Cognitive Psychology*, *23*(3), 457- 482.

Tardif, T. (1996). Nouns are not always learned before verbs: Evidence from Mandarin speakers' early vocabularies. *Developmental Psychology, 32*(3), 492-504.

Torkildsen, J. v. K., Syversen, G., Simonsen, H. G., Moen, I. & Lindgren, M. (2007a). Electrophysiological correlates of auditory semantic priming in 24-month olds. *Journal of Neurolinguistics, 20*(4), 332-351.

Torkildsen, J. v. K., Syversen, G., Simonsen, H. G., Moen, I. & Lindgren, M. (2007b). Brain responses to lexical-semantic priming in children at-risk for dyslexia. *Brain and Language*, *102*(3), 243-261.

Torkildsen, J. v. K. (2008). Lexical processing in typically and atypically developing toddlers: Insights from even-related potentials. Faculty of Humanities, University of Oslo.

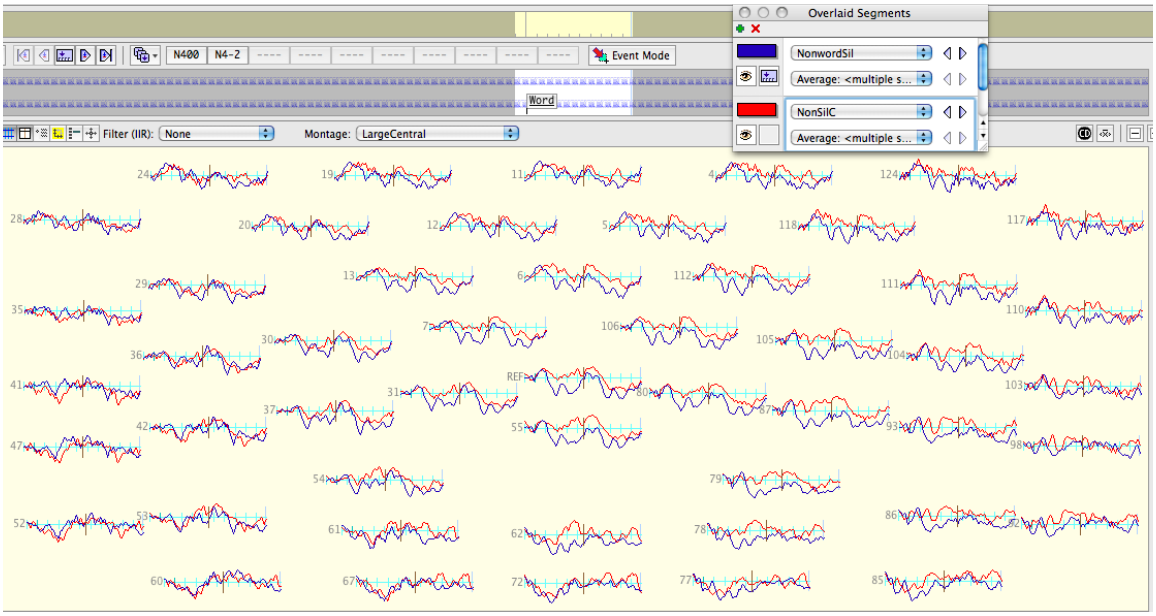
Torkildsen, J.K., Friis Hansen, H., Svangstu, J.M., Smith, L., Simonsen, H.G., Moen, I., & Lindgren, M. (2009). Brain dynamics of word familiarization in 20-month-olds: Effects of productive vocabulary size. *Brain and Language*, *108*(2), 73-78.

Werker, J. F., Cohen, L. B., Lloyd, V. L., Casasola, M., & Stager, C. L. (1998). Acquisition of word-object associations by 14-month-old infants. *Developmental Psychology*, *34*(6), 1289-1309.

Appendices

Figure 3.

Grand average waveforms for pseudowords for all subjects. Negative polarity is plotted up.

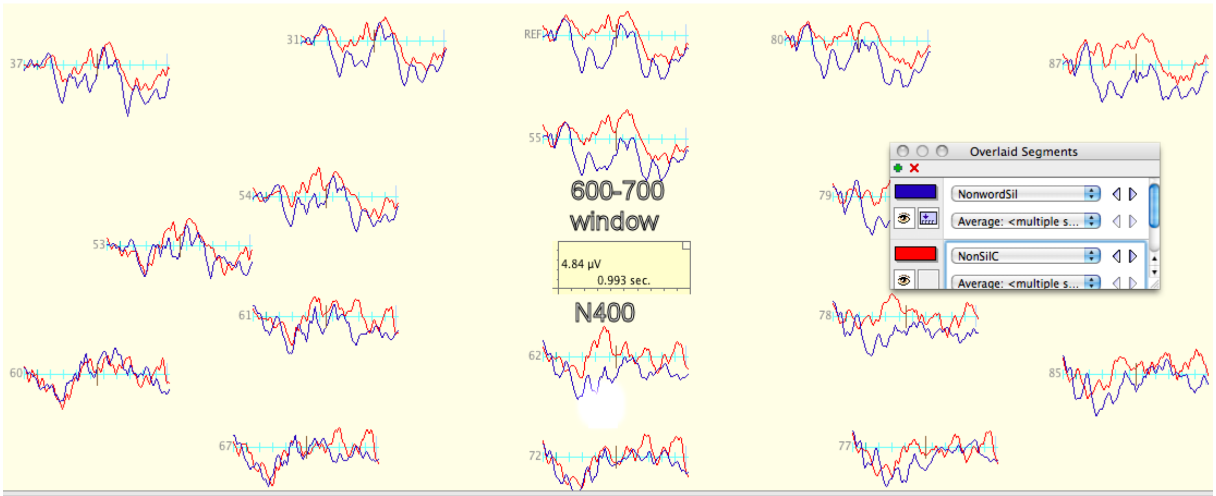


Blue lines: Pseudowords in the silhouette condition (congruent).

Red lines: Pseudowords in silhouette condition for incongruous presentations where there has been a semantic violation between words and pictures.

Figure 4.

Averaged waveforms for the parietal regions for all subjects for pseudowords in the silhouette condition. Negative polarity is plotted up.

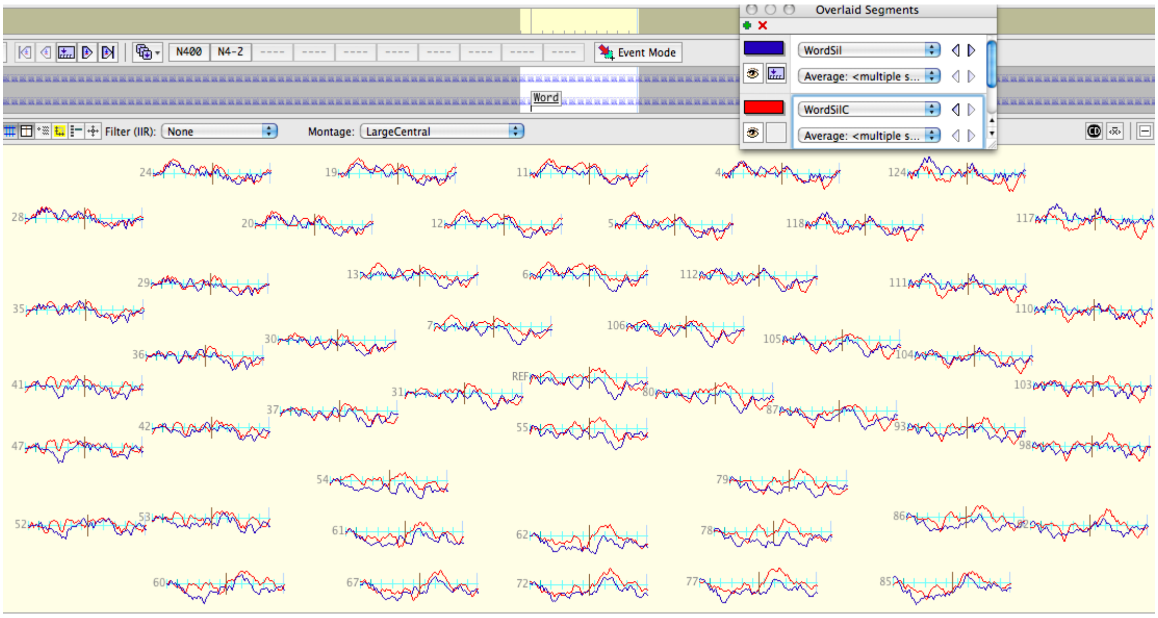


Blue lines: Pseudowords in the silhouette condition (congruent).

Red lines: Pseudowords in silhouette condition for incongruous presentations where there has been a semantic violation between words and pictures.

Figure 5.

Grand average waveforms for real words for all subjects. Negative polarity is plotted up.

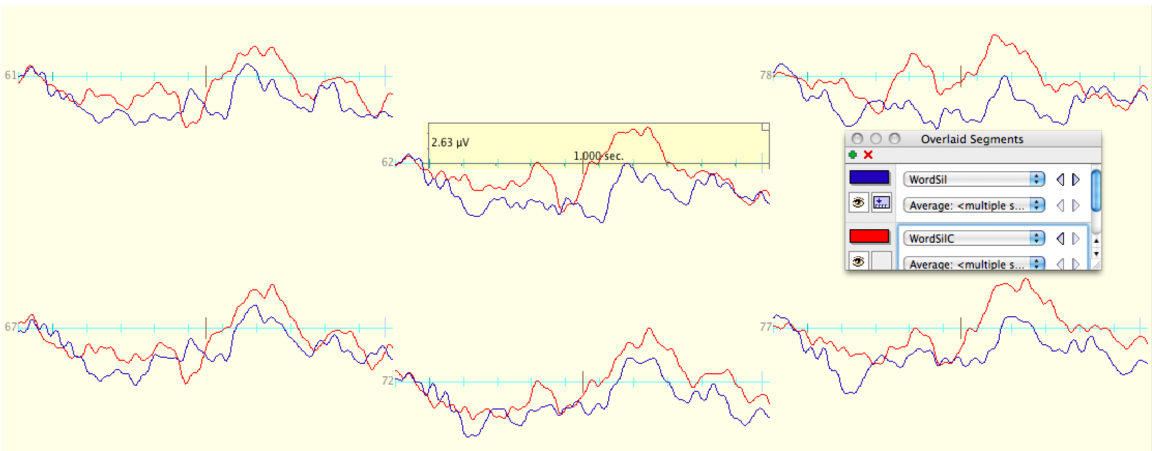


Blue lines: Real words. Silhouette condition (congruent).

Red lines: Real words. Silhouette condition for incongruous presentations where there has been a semantic violation between words and pictures

Figure 6.

Averaged waveforms for the parietal regions for all subjects in the real word condition. Negative polarity is plotted up.



Blue lines: Real words. Silhouette condition (congruent).

Red lines: Real words. Silhouette condition for incongruous presentations where there has been a semantic violation between words and picture.