Investigating early semantic priming: Event-related potentials as a window into the organization of word meaning in children at age 24 months.

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Abstract

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The present thesis is based on results from an experiment carried out as a part of a larger research project on semantic and communicative language development in children in their second year of life, initiated by Professor Lars Smith in corporation with Associate Professor Magnus Lindgren, at The department of Psychology, University of Oslo.

Background and Aim: Only at the onset of the second year are children able to form stable word-object associations and this point marks the beginning of a protracted period of semantic language development of which we know relatively little. The present event-related potential study aims to establish whether the language-related N400 component can be employed as an index of semantic priming in children at age 24 months. If so, the N400 component could potentially be of great value in investigations of the organization of word meaning at an early stage in language development. To address this issue an unimodal auditory semantic priming design was used.

Method: The subjects were presented for word stimuli consisting of semantically related and unrelated prime-target word pairs. In the related condition basic level words were taken from the same superordinate category (e.g. cat-horse). In the unrelated condition prime and target belonged to different superordinate categories (e.g. apple-table). The EEG was recorded with 30 silver-silverchloride electrodes attached to an elastic electrode cap.

Key result: Statistical analyses revealed a significant main effect of semantic relatedness in the 600-800 ms interval after stimulus onset, where unrelated words were more negative than related words.

Conclusion: The results demonstrated that in 24-month-old children target words which were preceded by a semantically unrelated word elicited a broadly distributed N400-like effect compared to target words which were primed by a semantically related word, suggesting sensitivity to semantic relatedness in this age group. The establishment of an N400-like semantic priming effect in the present experiment indicates that priming studies can be used as a functional tool in investigations of word meaning in toddlers and provides an opportunity to investigate semantic memory at a very early stage in development.

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Introduction

Word meaning in word learning

At twelve months most children start to respond meaningfully to words and they produce their first meaningful word in the same time range (Ingram, 1989; Bloom, 1994). In the task of fully recognizing a spoken word the language learner must segment the stream of speech sounds into units that can represent meaningful words and map these labels onto conceptual representations of the objects or states the word form may refer to.

Already from birth infants possess several of the speech perception capacities required for word learning. Only a few days old infants discriminates their native language from another (Mehler, Dupuox, Nazzi & Dehaene-Lambertz, 1996) and before six months they distinguish a wide range of phonemic contrasts made in natural language (Aslin, Jusczyk, Pisoni, 1998; Cheour et al., 2002; Dehaene-Lambertz & Pena, 2001; Eimas, Siqueland, Jusczyk & Vigorito,1971; Jusczyk,1992; Kujala et al., 2004). Around 8 months they show evidence of long-term storage of word forms that occur frequently in their native speech (Jusczyk & Aslin, 1995; Jusczyk & Hohne, 1997). However, the acquisition of a vocabulary requires long term retention of both verbal labels and their associated meanings. Children appear to first form stable connections between word and objects around the beginning of the second year (Woodward & Hoyne, 1999), adding to their productive vocabulary around 1 to 3 words a month. Between 18 and 24 months a sudden rise in vocabulary acquisition takes place where they can add as much as 20 new words a week (Fenson, Dale, Reznick, Bates, Thal & Pethik, 1994). This rise in vocabulary is associated with an accelerated understanding of categories and an improved ability to retrieve words from memory (Gershkoff-Stowe, Thal, Smith & Namy, 1997; Plunkett, 1993). Parent reports and diary studies have shown that children`s initial productive vocabulary include words from all the adult grammatical categories, though it primarily consists of common nouns (at least in English-speaking children) (Gleason & Pan, 2001; Mervis, 1983; Nelson, 1973).

It is not clear whether the first meanings children assign to words corresponds to adult meanings. Children under three years of age often use words in a manner that are inconsistent with the correct adult meaning of the word. There are especially two phenomena that give rise to believe that children's initial word meanings may differ from adults; the misuse of words often involve either overextension, where a child extends a term beyond the associated adult concept (e.g. say "dog" when seeing a cat) or underextension, where a particular word is used too narrowly to a restricted set of referents than are actually allowed by the adult concept (e.g. saying “dog” only in response to the family dog). Over- and underextension are common in the speech of one and two year olds and compromise up to one third of their productive vocabulary, however approaching the age of three these unconventional mappings are less frequent (Clark, 1993).

It is debated what extension phenomena can tell researchers about children’s early word meanings. Some have suggested that misextensions reveal mismatches between children’s early conceptual categories and those of adults, whereas others point out that children’s spoken words may not be a reliable reflection of underlying categorical structure (Hoek, Ingram & Gibson, 1986; Huttenlocker & Smiley, 1993; Mandler, 2004).

There is a well known gap between children’s first productive use of words and their actual comprehension of words, where productive vocabulary typically lags behind receptive vocabulary (Schafer & Plunkett, 1998; Woodward, Markman, & Fitzsimmons, 1994). In some studies maternal reports indicate that sixteen month olds can produce fewer than fifty words while at the same time comprehend well above 150 words (Bates et al., 1994). Hence, all unconventional productive use of words is not necessarily a sign of divergent underlying concepts between children and adults; over- and underextension might instead reflect an inability to find the correct word (retrieval problems) or not having acquired the correct label, although the underlying concept is identical.

Since productive vocabulary may give an inaccurate measure of children’s early understanding of word meanings, parental descriptive reports of production vocabulary is seldom used in investigation into these matters. Instead, researchers in language comprehension have used tasks where subjects have to point to or touch a picture or object when presented with a label. Unfortunately, these methods have the disadvantage that at least very young children does not always reliably point to or touch the objects that are named even though their looking behaviour suggest they recognize the referred object. In recent years researchers have employed the preferential looking paradigm to overcome difficulties related to using methods that are very dependent on subject`s cooperation and performance abilities (Golinkoff, Hirsh-Pasek, Cauley & Gordon, 1987; Hirsc-Pasek, Golinkoff & Hollich, 1999). In the preferential looking paradigm subjects hear spoken words or sentences presented at the same time as they watch two different simultaneous presented pictures or video sequences, where one picture or video sequence match the spoken word and the other represents a mismatch. Using this method, Naigles and Gelman (1995) for instance, found that although many of their subjects spontaneously called cows “dog”, when hearing the word “cow” while being presented for a video of a cow and a dog, they looked longer at the cow.

The wide use of the preferential looking technique clearly illustrates the worth of methods that avoid the use of overt performance measures when investigating language comprehension in very young children.

In adults, a frequently used method to examine the organisation of word meaning is semantic priming experiments. Priming refers the facilitated processing of a stimulus, as indexed by a decrease in reaction times and improved response accuracy, following a previous presentation of an identical or a related stimulus. Most believe that when a prime stimulus is encountered, information associated with the prime becomes available and influence the processing of the subsequently presented target item (Neely, 1991; Tulving & Schacter, 1990). Several types of relations between items have been shown to induce priming (Raposo, Moss, Stamatakis & Tyler, 2006). Relevant to the present study, manipulations of the semantic relation between words produce priming (Neely, 1977). A semantic relation between prime and target words has traditionally been defined as a relation that entails shared taxonomic category membership or overlap of semantic features (Balota, 1994; Hutchinson, 2003). For example, pizza and spaghetti are semantically related because they both belong to the same superordinate category (e.g. food).

A manipulation of the semantic relation between prime and target, is considered to offer a mirror into the type of information that becomes activated when the prime is processed, giving the possibility to draw inferences about the content and organisation of word meanings in semantic memory (Lucas, 2000). In the traditional and widely applied lexical decision task, where subjects are presented for a word pair (prime and target) and asked to indicate with a button press, if the target is a word or not, it is a well attested phenomenon that response latencies are reduced when a target word is preceded by a semantically related word, yielding what is called the semantic priming effect. In addition to behavioural semantic priming as measured by response latencies, one brain imaging method; the event-related potential technique, can yield a robust electrophysiological indicator of semantic priming (Osterhout & Holcomb, 1995). As reaction time measures are unfeasible with toddlers, this well established method gives an opportunity to investigate semantic priming in subjects that are too young to give a reliable behavioural response.

The event-related potential technique

Event-related potentials (ERPs) are an electrophysiological functional brain imaging measure, which inflicts no pain on the subjects, is non-invasive and easy to record. As the ERP method does not require an overt behavioural response and are relatively robust to motion, the technique is of especially fruitful use in very young subjects (Thomas & Casey, 2003; see De Boer, Scott & Nelson (2005) for a review). In recent years, ERPs have been successfully applied in studies investigating aspects of attention, face recognition and language-related processes in both infants and toddlers (Cycowicz, 2000; de Haan & Thomas, 2002; Taylor & Baldeweg, 2002). Although the preferential looking paradigm circumvents the difficulties of methods requiring an overt behavioural response, and thus has provided a great deal of important information on language learning in young children, this method lack the temporal accuracy offered by the event-related potential technique. Due to a superior temporal resolution, the measurement of event-related potentials enables a continuous observation of the brain's information processing online. In an event-related potential study brain activity is measured with electrodes fixed on the head's surface according to a predetermined system (the 10-20-system) based on anatomical landmarks. The scalp recorded electrical activity results in a trace of voltage fluctuations across time, known as an EEG (electroencephalogram) that primarily reflects electrical activity from post-synaptic potentials of cortical pyramidal neurons (Coles & Rugg, 1995).

The EEG is always composed of brain activity related and unrelated to presentation of stimuli, however repeated presentations enables the computation of an average of activity time–locked to stimulus presentation, presumably cancelling out unrelated activity or noise. The averaged waveform, called an event-related potential, is assumed to reflect brain activity associated with the stimulus events in question. ERPs can be described according to their polarity (positive or negative), latency (when after stimulus onset they occur), distribution on the head surface, functional properties and presumed neural generator. In the characterization of event-related potentials, researches typically focus on some of the features mentioned above, defining the waveform in terms of a component (Otten & Rugg, 2005).

The N400 component

The N400 component, a late centroparietally peaking ERP waveform with a typical latency of 400 milliseconds (ms), is believed to be especially sensitive to manipulations of semantic information. The vast amount of research using the N400 as a dependent measure is primarily composed of studies investigating the time-course of context effects in written sentence processing, and single word and word-pairs studies examining aspects of organization and access into semantic long-term memory (Kutas & Federmeier, 2000). The N400 was first described in a seminal study by Kutas and Hillyard (1980) as a response to semantically anomalous ending words in a sentence processing paradigm. Subjects read visually presented syntactically correct sentences where the meaning of the ending word was either semantically inappropriate (”He took a sip from the waterfall”) or semantically appropriate but physically aberrant (”She put on her high heeled SHOES”). Semantically inappropriate ending words elicited a negative potential, with a peak latency of 400 ms, relative to semantically appropriate control words. Kutas and Hillyards (1980) original report generated a wave of studies investigating task-related modulations of the N400 component. The sentence N400 semantic incongruity effect is seen across a variety of languages and has been observed to semantic incongruities in American Sign Language (Kutas & Van Petten, 1994). The N400 is primarily restricted to the semantic domain and is not a general response to linguistic anomalies, such as violations of the grammatical or phonological properties of the presented words (Kutas & Federmeier, 2000).

The N400 and semantic priming

Although the initial discovery of the N400 was in a sentence processing paradigm the component has been identified in experiments using single words in lists or word pairs as stimuli. Bentin, McCarthy and Wood (1985) were among the first to report a N400 component in the lexical decision task. They presented their subjects for targets related to the prime (identical semantic category) and targets unrelated to the prime (different semantic category). They found, in addition to the expected reduction in reaction time to related targets, that unrelated targets elicited a negative-going wave with a peak latency at 400 ms, compared to the related targets.

Semantic priming effects on N400 amplitude have later been seen in a variety of word-pair experiments (Anderson & Holcomb, 1995; Bentin, 1987; Bentin, Kutas & Hillyard, 1993; Holcomb, 1988; Holcomb & Neville, 1990; Rossel, Price & Nobre, 2003; Rugg, 1985). By now, it is a well-established finding that the N400 is modulated by the semantic relation between pairs of words, its amplitude being attenuated by prior exposure to a semantically related word. If the semantic relation between words is decided in terms of category membership, in the context of wordlists, out of category words elicit a larger N400 compared to words from a preceding established category (Boddy, 1981; Neville, Kutas, Chesney & Scmidt, 1986). In addition, it has been shown that among words that fit a certain category (e.g. bird), atypical members (e.g. ostrich) elicits larger N400 amplitude than typical members (e.g. pigeon) (Heinze, Muente & Kutas, 1998). This modulation by categorical relations is further found in sentence studies and has largely been construed as an index of the N400 components sensitivity to long-term semantic memory organisation (Federmeier, Devon, McLennan, Ochoa & Kutas, 2002; Federmeier & Kutas, 1999).

Although the N400 component are modulated by experimental designs created to induce semantic priming it is important to note that interpretation of semantic priming effects is disputed (Ferrand & New, 2003; Hutchinson, 2003; Lucas, 2000), both in terms of what kind of relation between target and prime really produce priming, on what level in the cognitive structure the priming occurs and what type of processing a specific experiment design engages. Similar disagreements surround explanations of the N400 semantic priming effect. Fischler (1977) was among the first to raise the question if "semantic priming effects" were truly semantically mediated. He stressed that there was, at least, a theoretical distinction between what is called associative and semantic relations. The facilitative effect of a prime word on the subsequent identification of a related target word has been described both as an effect of association, i.e. an associative relationship between prime and target, (Meyer and Schvaneveldt, 1971) and as a semantic facilitation effect (Neely, 1977), i.e. a semantic relationship between prime and target. Associative relatedness is a normative description of the probability that one word will call into mind a second word (Postman & Keppel, 1970). Associative relations are thought to be based on the frequency of co-occurrence of two concepts' names. The source of these associations might be temporal contiguity or co-occurrence of words in verbal or written propositions (Balota, 1994). In contrast, semantic relations can be understood as a relation between words in terms of similar semantic features or a relation that entails subordinate category relations. Many early reported semantic priming experiments had used very strongly associated word pairs in the related condition, thus consequently giving reason to question whether reported semantic priming effects really were due to semantic relatedness (Hutchinson, 2003; Lucas, 2000).

Both in the behavioural and erp-literature on semantic priming one has usually employed related prime target pairs that has been strongly associated at the same time as sharing many semantic features, such as categorical associates (e.g. fork-knife) or category instance relations (e.g. dog-chiuawa). Hence, it has been difficult to separate effects produced by the strong association between the words and effects of semantic similarity (Balota, 1994; Schwanenfugel, 1991). Behavioural studies which have attempted to tease apart semantic from associative relations have found that both relation types have an independent effect on priming (Perea & Rosa, 2002). In one ERP study, both lexically associated and semantically similar words produced the N400 semantic priming effect, indicating that both type of relations was sufficient, but not necessary to yield a priming effect (Koivisto & Revonsuo, 2001).

In addition to questions regarding associative and semantic relation effects on priming, a related and often addressed issue in the literature is whether priming occurs on a lexical or conceptual level. The word recognition system is often referred to as a lexicon, which is seen as that aspect of semantic memory that is specialized for the storage and processing of information about words, which can be separated from, but are highly interconnected to a conceptual level in long-term semantic memory. In spite of some variation, most models accounting for word recognition separate between a conceptual or semantic level representing word meaning and a lexical level, where phonological and orthographic information about words are represented (Lucas, 2000). In both behavioural and ERP studies semantic priming effects have been reported in designs involving pair of pictures (Barrett & Rugg, 1990), sentences in combination with words (Federmeier & Kutas, 1999), combination of pictures and written words (Nigam, Hoffman & Simons, 1992) and combination of written and spoken words (Holcomb & Anderson, 1993), suggesting that priming occurs both between and within modalities. Depending on the experimental paradigm, there is a theoretical possibility that priming occurs on the lexical level or emanates from activity on a higher conceptual level (Tabossi, 1991). Some assume that there is a link between type of priming relation (associative vs. semantic) and processing level (lexical vs. conceptual) such that priming produced by different relation types reflects processes at different levels (Perea & Gotor, 1997; Perea & Rosa, 2002). For instance, one assumption is that both pure categorical (e.g. cat-elephant) and categorical associate (e.g. cat-mouse) priming solely reflects semantic processes at a conceptual level, whereas associative (e.g. dog-bone) priming specifically reflects associative processes at the lexical level (Lucas, 2000; Lupker, 1984; Shelton & Martin, 1992). Further, associative priming have been thought to occur at the conceptual level due to the frequency of co-occurrence of the objects that the concepts represent (Perea & Rosa, 2002). In addition, it is debated whether the lexical level is organized semantically. For instance, in a unimodal word-pair priming experiment, priming effects can been assumed to be entirely lexical if one accepts the idea of a semantic organization of the lexicon (Tabossi, 1991).

Another frequently occurring theme in the literature on semantic priming is whether the priming effects are due to automatic or controlled thought processes. In the ERP-litterature many types of priming mechanisms has been forward as underlying the N400 semantic priming effect. Most mentioned of these are automatic spreading activation and expectancy-based or attentional priming and they are both thought to contribute in the generation of the N400 in word-pair studies (Neely, 1991; Osterhout & Holcomb, 1995; Stenberg, 2000). Priming mechanisms are roughly divided into two main types and depending on specific features of the experimental design, priming is assumed to be realized by either automatic or controlled processing. The automatic spreading activation mechanism refers to an automatic process that is fast-acting, occurs without intention or conscious awareness and is unlimited in capacity. In contrast, expectancy-based or attentional priming are realized by a controlled process which is slow-acting, operates with intention and is limited in capacity. Semantic priming effects are thought to reflect an automatic spreading activation process in experimental circumstances that exclude conscious processing of the prime, such as short prime-target onset asynchronies (SOAs) (less than 400 ms) (Neely, 1977) or when related primes occurs infrequently throughout the experiment (de Groot, 1984). Controlled processing mechanisms, on the other hand, are engaged in conditions with long SOAs and a high proportion of related prime-target pairs. These are manipulations that can encourage the processing of a prime as a predictor of a subsequent target, such that expectancies about words are used strategically to direct attention to a limited domain of related meanings in memory. Studies that have specifically investigated whether the N400 effect is sensitive to automatic spreading activation have found that the N400 effect is present in conditions with very short SOAs (Boddy, 1986). It is also found in studies with simultaneous presentations of prime and targets (Anderson & Holcomb, 1995) and in sleep (Brualla, Romero, Serrano & Valdizan, 1998). Results from studies using masked priming, a procedure which prevents attentive processing of the prime, provide conflicting results, where some (Brown & Hagoort, 1993), but not all (Deacon, Hewitt, Yang & Nagata, 2000; Stenberg, 2000) have failed to find a semantic priming effect to related targets. By varying the proportion of related word pairs and instructions given to subjects Holcomb (1988) found that task instructions and manipulations, that either induced their subjects to strategically attend to the semantic relationship between prime and target or provoked only automatic priming, both gave rise to an enhanced N400 to unrelated targets that were larger in the attention condition.

To sum up, the N400 component is modulated by a variety of factors, such as semantic anomaly (incongruence), semantic relatedness and associative relatedness. In addition, the amplitude of the N400 reflects a word's usage frequency (Rugg, 1990; Van Petten & Kutas, 1990) and is reduced with repetition (Holcomb, Anderson & Grainger, 2005; Van Petten, Kutas, Kluender, Mitchiner & McIsaac, 1991). This has made the component difficult to interpret in terms of one single underlying cognitive process. Van Petten & Kutas (1991) has proposed that the N400 component represents the brains default response to words that can be reduced by all the factors mentioned above. The most common interpretation of the N400 component assumes that it reflects the contextual integration involved when subjects relate the semantic representation of a single word to a semantic representation of prior contextual input (Kutas & Federmeier, 2000).

However, recent studies indicate that almost any type of meaning-carrying stimuli is associated with a negative modulation around 400 ms after stimulus onset. For instance, N400-like negativities has been reported during the processing of semantically unrelated pictures (Barrett & Rugg, 1990), faces (Barrett & Rugg, 1989) and environmental sounds (Van Petten & Rheinfelder, 1995). Rather than reflecting activity from a single area in the brain, the N400 component is assumed to echo activity from a distributed network of regions involved in contextual integration. In this regard it is important to note that the N400, depending on specific features of the paradigms used, tends to differ in scalp topography across experiments (Fogelson, Loukas, Brown & Brown, 2004).

The N400 component in children

There are a number of cross-sectional studies investigating the N400 in children from around five years and upwards. The primary focus in these investigations has been a comparison of the effect of sentence context on the processing of single words in children and adults (Hahne, Eckstein & Friederici, 2004; Holcomb, Coffey & Neville, 1992; Juottonen, Revonsuo & Lang, 1996; Silva-Pereyra, Klarman, Lin & Kuhl, 2005; Silva-Pereyra, Rivera-Gaxiola & Kuhl, 2005). Results from these reports indicate that the N400 elicited in response to semantically anomalous ending words are more pronounced and have longer peak latency in children while scalp topography seems largely stable after pre-school age. The age-related decline in latency is explained in terms of a developmental increase in the speed with which semantic information is processed (Federmeier et al., 2003).

The N400 has only recently been applied as a dependent measure in language studies in children in their second year of life (Friedrich & Friederici, 2004, 2005a, 2005b, 2005c; Mills, Conboy, & Paton, 2005; Torkildsen, Sannerud, Syversen, Thormodsen, Simonsen, Moen, Smith & Lindgren, 2006; Torkildsen, Syversen, Simonsen, Moen & Lindgren (in press). Note that in these studies the component is interpreted as a functional equivalent to the traditional adult N400 although both latency and distribution tends to differ from the adult N400. More specifically, across studies, the component usually has a delayed latency (ranging from 400 to 800 ms after stimulus onset) and sometimes has a more left-lateralized frontal distribution.

The few studies conducted in toddlers have primarily used a picture-word matching design, creating an experimental analogue to a pointing book situation, where subjects first are presented with a picture of an object followed by either a semantically incongruent (e.g. cat-dog) or congruent (e.g. cat-cat) auditory presented word. The first to report an N400-like semantic incongruity effect were Friedrich & Friederici (2004) in a study with 19-month olds. Their study addressed whether adult-like mechanisms of semantic processing, as indexed by the N400, could be demonstrated in the earliest stages of language acquisition. Subjects were presented for two types of picture-word pairings where picture and word in the congruent condition where identical, whereas they were different in the incongruent condition. Friedrich and Friedrici (2004) found that compared to congruous words, incongruous words elicited a long-lasting negative response, with a slight left lateralized parietal distribution starting around 400 ms, reaching a maximum effect around 800 ms after stimulus onset. A replication of this initial study yielded similar results with 14-month olds (Friedrich & Friederici, 2005a).

In one study, using an equivalent picture-word matching design, Torkildsen et al. (2006) further explored whether the observed semantic incongruity response could be proven sensitive to the degree of the semantic relatedness between the presented pictures and words. The study by Friedrich and Friedrici (2004) firmly established that an N400-like effect could be observed to a general semantic incongruity between a picture and word, but there were no indications as to how the words and pictures in the semantic incongruity condition differed, i.e. if the basic-level words differed in terms of coming from a different superordinate category (e.g. cat-table) or if they differed, but still belonged to the same superordinate category (e.g. orange-banana). Torkildsen et al. (2006) reasoned that a manipulation of the degree of semantic relation between the presented pictures and words could provide important information about the organisation of word meaning that was missed by the previous investigations. Children at the age of 20 months were presented to three picture-word combinations, a between-category condition (e.g. cat-apple), a within-category condition (e.g. cat-frog) and a congruent control condition (e.g. cat-cat). Results indicated that ERPs in both conditions elicited a semantic incongruity effect resembling the N400 found in adults. However, compared to the control condition, the incongruity response was stronger and earlier for between-category words than the response to within-category words, which appeared later and had a more narrow distribution on the head surface.

Aim of the present study

The previous studies on the N400 in children have in common that they measured the component as an index of a general semantic incongruence, either presenting pictures in combination with words or sentences in combination with words. As mentioned in the introduction, the N400 is modulated by a variety of experimental designs. In addition to being sensitive to a general semantic incongruence between presented stimulus items, the N400 has also been shown to be sensitive to the degree of the semantic relatedness between words in semantic priming experiments. These have repeatedly shown a semantic relatedness effect on the N400 component, such that the amplitude to a target word is reduced by prior exposure to a semantically related prime word. To date, a similar finding of a N400 semantic priming effect in a unimodal design has not been shown in toddlers.

Investigating the N400 semantic priming effect in very young children would provide the opportunity to preliminary establish whether the N400 component is functionally equivalent in adults and children. If so, the N400 component could potentially be of great value in investigations of the organisation of word meaning at an early stage in language development. Additionally, it would point to the possibility for comparing findings across ages using the same measurement paradigm.

It is important to note that in adults, the N400 semantic priming effect has been investigated in the context of the lexical decision task, relying on a visual presentation of written words. An assessment the N400 semantic priming effect in two year olds necessitates a modification to a passive listening of auditory presented words. In adults, a similar modification might be expected to alter the pattern of the N400, as some studies have reported differences between N400s to written and auditory presentations of words (Holcomb & Neville, 1990; Anderson & Holcomb, 1995). However, an auditory presentation of words would not induce changes masking the basic difference in amplitude to related and unrelated words.

The purpose of the present study is to determine if the differential processing of unrelated and related target words, as measured by the N400 component, can be observed in the scalp-recorded event related potentials of 24-month olds, in a unimodal auditory semantic priming experiment, using basic-level nouns as stimuli.

Method

Participants

24 (12 boys) children at the age of 24 months (+/- 14 days) from monolingual Norwegian-speaking homes participated in the study. The subjects were recruited through newspaper advertisements and received a small compensation for participation.

Parents signed an informed consent form prior to testing and answered a questionnaire about pregnancy, birth, illnesses and possible disabilities of the child. They also completed the Norwegian adaptation (Smith, unpublished) of the MacArthur-Bates Communicative Development Inventory (MCDI) (Fenson et al., 1993) one week prior to EEG-testing. The children were full term (>36 weeks of gestation) and healthy, and had no known neurological problems. No family history of dyslexia or other language impairments were reported in any of the subjects. All parents were right handed. Upon completion of the experiment participants were fully debriefed. The study was approved by an ethical committee.

Stimuli

Word stimuli were 70 common one-, two- and three-syllable basic level nouns, taken from the Norwegian adaptation (Smith, unpublished) of the MCDI (Fenson et al., 1993).

The items were selected with the intention that 24-month old children would be able to comprehend them. According to parental responses on the MCDI, children in the final sample had a mean productive vocabulary of 337.7 words (*SD* = 198.3 words, range from 40 to 676 words). On average participants produced 49 of the 70 words used in the experiment. Considering the fact that receptive vocabulary usually outsizes expressive vocabulary in this age-group (Bates et al., 1994) it is plausible that most of the items selected were comprehended by the participants. This approach to stimuli selection is in line with previous studies (Friedrich & Friederici, 2004, 2005a, 2005b, 2005c; Torkildsen et al., 2006).

Items from the following superordinate categories were included: animals, food, clothes, body parts, furniture and vehicles. The words had a mean duration of 700 ms and were spoken in a natural, female voice, digitized at 16 bits with a 44, 1 kHz sampling rate, presented at an intensity of 70 dB SPL.

The words were grouped in pairs and divided into two conditions: (1) a related condition, where prime and target belonged the same superordinate category (e.g. cat-snake) and (2) an unrelated condition, where prime and target belonged to different superordinate categories (e.g. cat-orange). All participants were presented to the same randomized mix of related and unrelated prime-target pairs.

Procedure

The total experimental session lasted about 8 min. During the EEG recordings, participants were seated on their parent's lap, in front of a 30 x 40 cm computer monitor in a electrically shielded and sound-insulated experimental room. The parents were instructed to be silent and unresponsive if the child initiated contact. Speakers and monitor were placed 1 m in front of the participants. A curtain blocked every object except the speakers and computer screen from view. All participants were video-monitored during the experiment and their behaviour was continuously observed. They were given a short break if they displayed signs of excessive discomfort. To keep the participant's attention during the experimental session a visually presented filler image appeared on a computer screen before each prime-target trial. The filler images were four different pictures of cartoon-like characters. The same picture was displayed every four trials. Prior to the presentation of the word stimuli the participants were visually introduced to each of the characters and simultaneously heard the following statement over the loudspeakers: "Now you'll se four characters. These characters will say some words to you. Listen carefully to what they have to say." During the stimuli presentation the filler image appeared for 1000 ms before the screen went blank. After a 1000 ms pause the prime was presented. Prime-target inter-stimulus interval was 1200 ms. After a 1200 ms inter-trial interval a different filler image appeared on the screen and the procedure was repeated.

EEG recording

The EEG was continuously recorded from 30 silver–silver chloride electrodes at sites Fp1, Fp2, F7, F3, Fz, F4, F8, FT7, FC3, FCz, FC4, FT8, T3, C3, Cz, C4, T4, TP7, CP3, CPz, CP4, TP8, T5, P3, Pz, P4, T6, O1, Oz, O2, according to the 10–20 International System of Electrode Placement, attached to an elastic electrode cap (Easy Cap, Falk Minow). The vertical electrooculogram (VEOG) was recorded from supraorbital (X1) and infraorbital (X2) electrodes on the right eye and the horizontal electrooculogram (HEOG) from electrodes located lateral to the left (X3) and right eye (X4). Impedances were kept below 5 kΩ and all electrodes were referenced to the average of the left (A1) and right (A2) mastoids. The EEG was amplified through a Neuroscan Nuamps amplifier digitized on-line at a rate of 500 Hz (digital filter from 0.1-70 Hz). The total time to complete administration of electrodes and impedance measures was about 30 minutes.

EEG analysis

A zero-phase digital band-pass filter ranging from 0.3 (12dbO) to 20 Hz (12dbO) was applied to the EEG. Epochs of 1200 ms were computed with a prestimulus interval of 100 ms. The epochs were baselinecorrected according to a 100 ms prestimulusinterval. Due to excessive movement artefacts, seven subjects were excluded from further analysis, leaving 17 subjects in the final sample. Before averaging, epochs containing amplitudes exceeding a standard deviation of 150 mikrovolts were automatically rejected (all channels, including HEOG and VEOG). At least 20 artifact-free trials were required for an individual average to be included in statistical analyses. The mean number of accepted trials was 27.8 (*SD*=1.4).

After visual inspection of the grand average ERPs nine areas of interests were selected for further statistical analyses: left frontal (F3, FC3), midline frontal (Fz, FCz), right frontal (F4, FC4), left central (C3, CP3), midline central (Cz, CPz), right central (C4, CP4), left parietal (P3), midline parietal (Pz) and right parietal (P4).

Since the few studies investigating the N400 in comparable age groups have reported a substantial variation in the latency of the component, there were no a priori assumptions made regarding specific time-windows to include or exclude from statistical analysis. Instead, in line with previous studies (Friedrich & Friederici, 2004, 2005a, 2005b, 2005c; Torkildsen et al., 2006), the effect of the experimental manipulation was analyzed using mean amplitude values in consecutive time intervals of 200 ms, from 200-1200 ms.

Statistical analyses

Mean amplitude values in each pre-selected time window were submitted to three-way repeated measures ANOVA with condition (related, unrelated), laterality (left, midline, right) and region (frontal, central, parietal) as within-subject factors. Separate two-way repeated measures ANOVAs was also applied to each selected time window for each of the three laterality domains (left, midline, right) and each of the three regions (frontal, central, parietal). Significant interactions were followed up by one-way ANOVAs.

An alpha level of 0.05 was used. The Greenhouse-Geisser correction (Greenhouse & Geisser, 1959) was applied when evaluating effects with more than one degree of freedom in the numerator.

To ensure that differential responses to unrelated and related target words were solely dependent on the relationship to the prior presented prime, it was important to investigate whether the initial response to the prime words was similar across conditions.

In order to establish that there were no statistical significant differences in the initial response to prime words used in each of the conditions, mean amplitude values to the prime words were submitted to a three-way repeated measures ANOVA with condition (related, unrelated), hemisphere (left, midline, right) and region (frontal, central, parietal) as within-subject factors.

Results

Primes

Visual inspection of the grand average ERPs in the nine areas of interests, established clear similarities between the potentials elicited to the primes in the different conditions. Both related and unrelated primes were characterized by a pronounced positive deflection around 150 ms after prime-onset, followed by two negative deflections in the time interval from 200-650 ms. Over the left hemisphere the first negative deflection was of weak amplitude and lasting from 200 to 400 ms, whereas the second, which lasted from 400 to 650 ms, had a clearly visible large amplitude peak around 500 ms. Over the midline and right hemisphere the difference between the two negative deflections was less pronounced.

There were no significant differences between words that primed related targets and words that preceded unrelated targets in any time interval (F (1,16) = 0. 17- 0.44, p = 0.68- 0. 51, η^2 = 0.01-0.02).

Targets

Visual inspection of the grand average ERPs in the areas of interest, showed a pronounced positive deflection around 150 ms after stimulus onset, in both conditions and on all electrodes. In the time interval from 200 to about 500 ms unrelated targets were generally more positive than related targets over all electrodes. Conversely, related targets were more negative than unrelated targets in this time interval. The most prominent demarcation between related and unrelated targets could be seen in the time interval from 600 to 800 ms after stimulus onset, where the response to unrelated targets were characterized by a clearly visible negative deflection, compared to related targets. This later negativity to unrelated targets had a wide distribution, however; it started earlier, around 500 ms, and was more pronounced, over the left hemisphere and midline sites, as compared to the right hemisphere sites. At parietal sites no visible differences between the two target types could be observed.

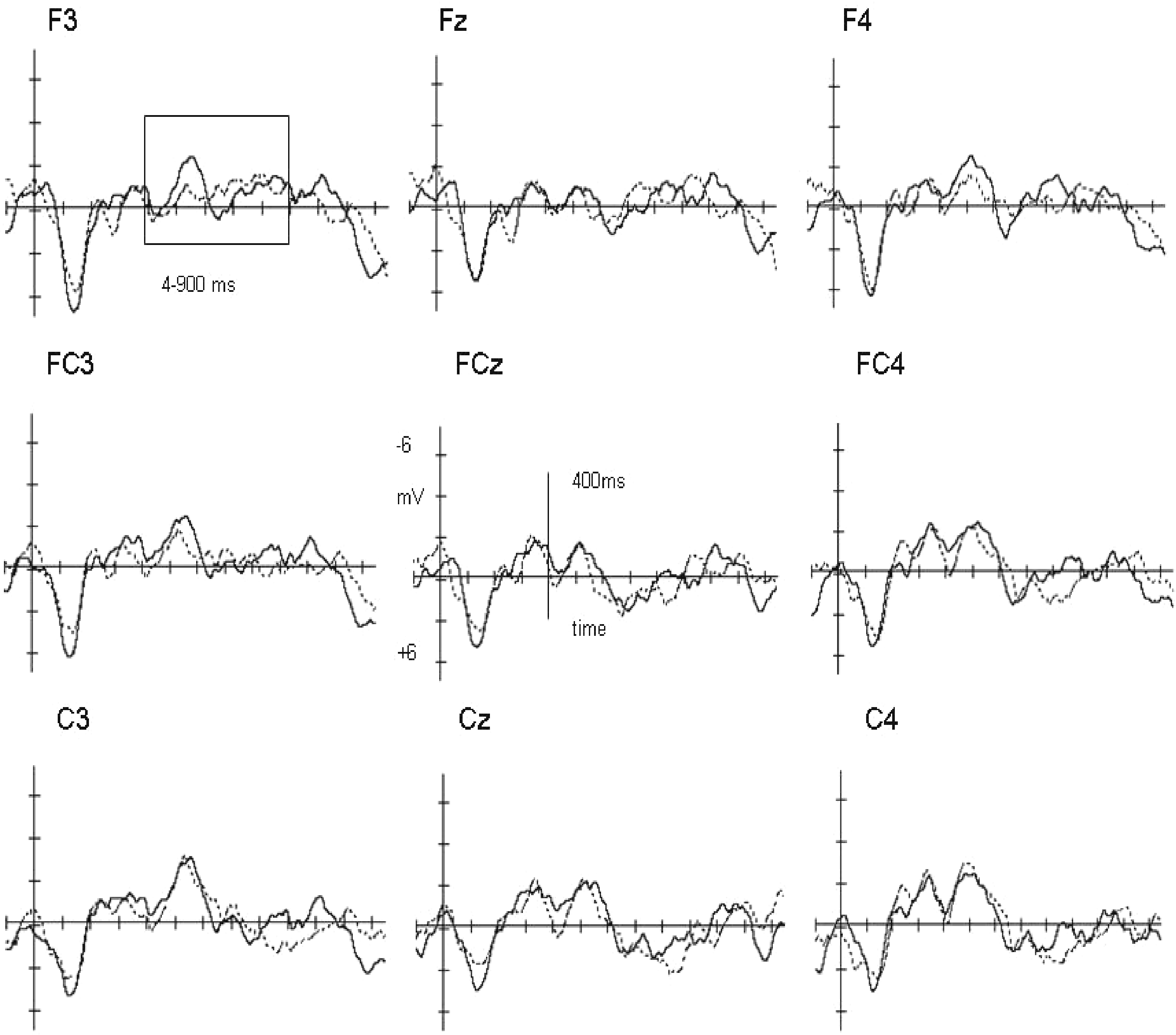

Figure 1. Grand average ERPs for prime words in the related (dotted lines) and unrelated condition on a selection of frontal and central electrodes. Negative amplitude-values up.

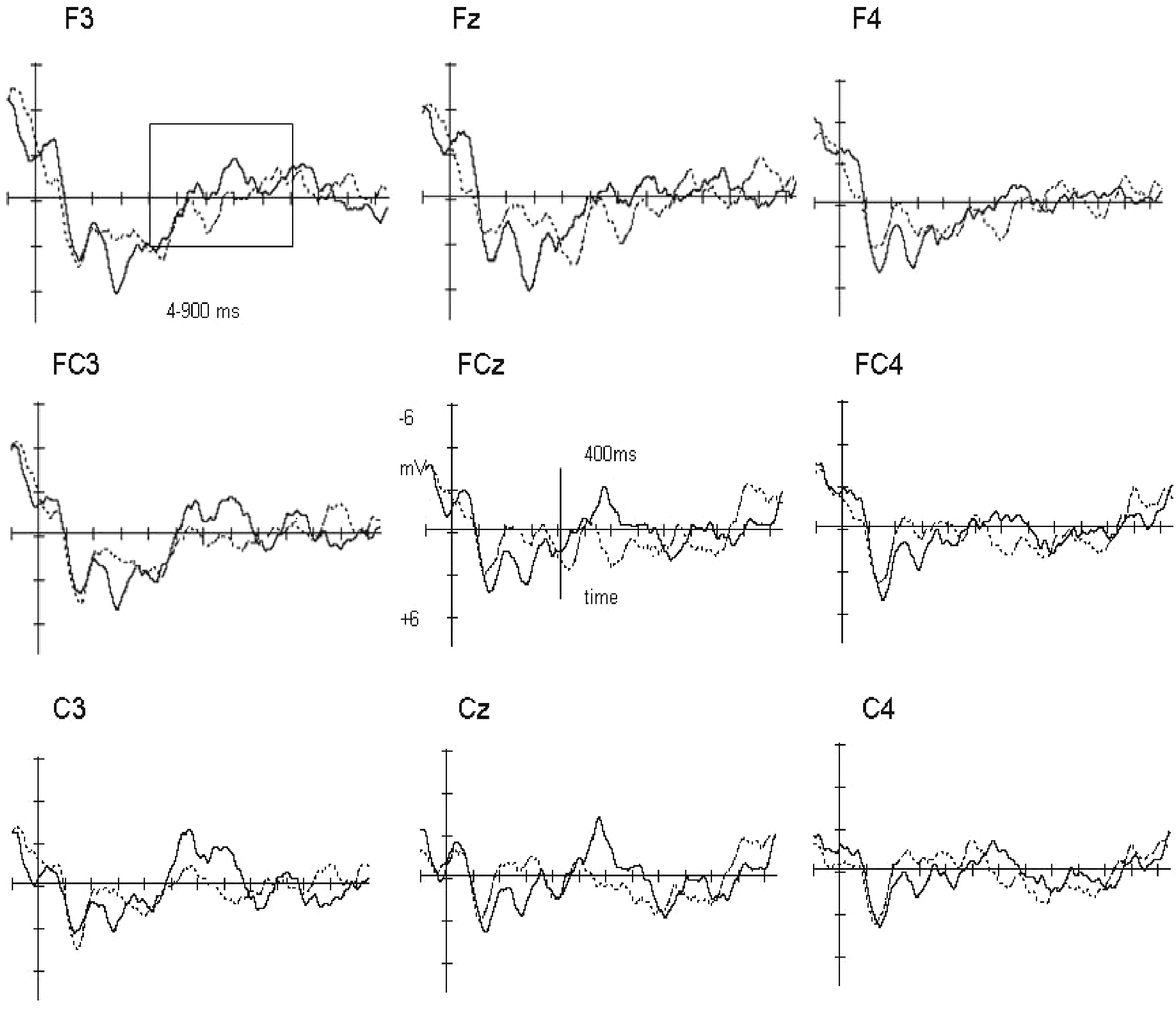

Figure 2. Grand average ERPs for target words in the related (dotted lines) and unrelated condition on a selection of frontal and central electrodes. Negative amplitude-values up.

Effects of target type in the 6 predefined time intervals.

In the most early time interval from 0 to 200 ms no significant main effects of the experimental manipulation were observed (F (1, 16) = 0.30, p = 0.58 η^2 = 0.18).

In the 200 to 400 ms interval related words were more negative than unrelated words (condition main effect (F (1, 16) = 6.17, p= 0.02 η^2= 0.278). Separate two-way ANOVAs for the three different regions (frontal, central, parietal) were performed. In the frontal region there was a significant condition main effect (F (1, 16) = 6.16, p= 0.02 η^2 = 0.27). In the central region a significant condition main effect (F (1, 16) = 11.91, p = 0.003 η^2 = 0.42) and a significant condition*laterality interaction (F (2, 32) = 13.19, p= 0.0005 η^2 = 0.45) were observed. In the parietal region no significant main effect of condition (F (1, 16) = 2.70, p = 0.12 η^2 = 0.14) was found. One-way follow up ANOVAs of the condition*region interaction in the central region, established that the effect of condition was strongest in the right central region (F (1, 16) = 6.99, p= 0.01 η^2 = 0. 30), robust in the midcentral region (F (1, 16) = 5.75, p= 0. 02 η^2 = 0.26) and moderate in the left central region (F (1, 16) = 4.43, p= 0.051 η^2 = 0.27).

In the 400 to 600 ms interval no main effect of condition was found (F (1, 16) = 0.356, p= 0.55 η^2 = 0.02) However, a significant condition*region interaction (F (2, 32) = 4.45, p= 0.02 η^2 = 0.21) and a significant condition*hemisphere interaction (F (2, 32) = 4.91, p= 0.02 η^2 = 0.23) were observed. Separate two-ways ANOVAs for the three different regions (frontal, central, parietal) yielded a significant condition*hemisphere interaction (F (2, 32) = 3.90, p= 0.03 η^2 = 0.19) in the frontal region. No condition main effects were found in the central region (F (1, 16) = 0.34, p= 0.56 η^2 = 0.02) or the parietal region (F (1, 16) = 0.68, p = 0. 42 η^2 = 0.04). For the three different laterality domains (right, midline, left) it was established a significant condition*region interaction (F (2, 32) = 7.72, p= 0.002 η^2 = 0.032) in the midline. No condition main effects were found in the right (F (1, 16) = 0.02, p= 0.96 η^2 = 0.00) or left hemisphere (F (1, 16) = 0.98, p = 0.33 η^2 = 0.05. One-way follow up ANOVAs of these interactions revealed a robust effect of semantic relation in the frontal midline area (F (1, 16) = 5.24, p= 0.03 η^2 = 0.24) where unrelated words were more negative than related words.

In the 6-800 ms interval unrelated targets were more negative than related targets (condition main effect (F (1, 16) = 6.53, p= 0.02 η^2 = 0.29). Separate two-ways ANOVAs of the three different hemisphere domains yielded a significant condition main effect (F (1, 16) = 7.26, p=0.01 η^2 = 0. 31) in the left hemisphere and a significant condition main effect (F (1, 16) = 4.50, p= 0.05 η^2= 0.22) in the midline. In the right hemisphere a near-significant main effect of condition (F (1, 16) = 3.96, p= 0, 06 η^2 = 0.19) was observed. Separate two-ways ANOVAs of the three different regions yielded a significant condition main effect (F (1, 16) = 11.43, p= 0.004 η^2= 0. 41) in the frontal region and a significant condition main effect (F (1, 16) = 7.92, p= 0.01 η^2= 0.33) in the central region. In the parietal region no main effects (F (1, 16) = 0.83, p= 0.37 η^2= 0.05) could be established.

In the remaining late time intervals no significant condition main effects were observed (800-1000 ms: (F (1, 16) = 0.06, p = 0.80 η^2 =0.004, 1000-1200 ms: (F (1, 16) = 2.06 p= 0.17 η^2= 0.11).

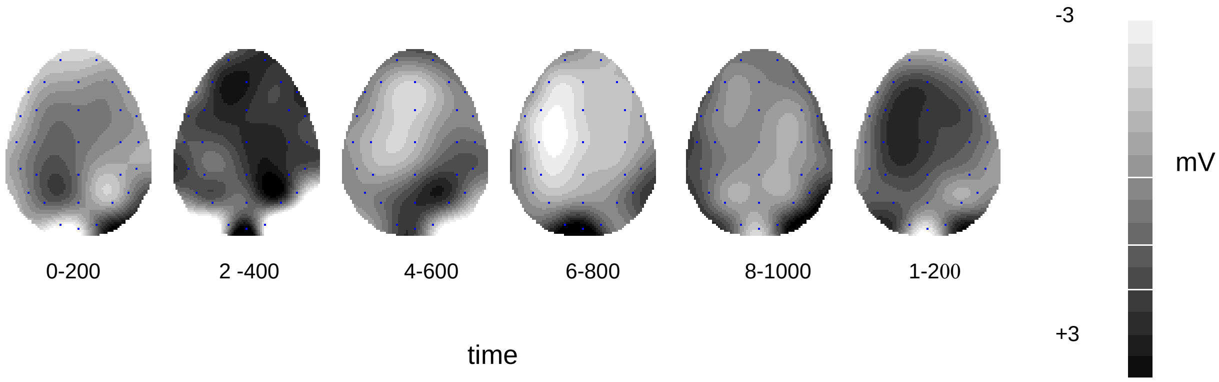

Figure 3. Spatial distribution map of the grand average difference waves between unrelated and related target words within consecutive time intervals of 200 ms. Grand average difference waves are formed by subtracting mean amplitude values in one condition (i.e. related targets) from mean amplitude values (i.e. unrelated targets) in another condition.

Table 1

Mean amplitude values (collapsed over all electrodes included in the statistical analyses) for targets words in each condition in each time interval (N=17).

	Condition	
Time interval	Related targets	Unrelated targets
0-200 ms	0,60 (*SD* 2,67)	0, 43 (*SD* 3,33)
200-400 ms	-0,58 (*SD* 2,48)	1,13 (*SD* 2,30)
400-600 ms	-0,07 (*SD* 4,70)	-0,69 (*SD* 5,05)
600-800 ms	1,13 (*SD* 2,74)	-0,62 (*SD* 3,30)
800-1000 ms	0,55 (*SD* 2,46)	0,34 (*SD* 2,57)
1000-1200 ms	-0,65 (*SD* 1,5)	0,33 (*SD* 3,28)

Discussion

In adults, the N400 component is elicited in response to semantically incongruent or anomalous ending words in sentence processing studies (Kutas & Hillyard, 1980; 1983; 1984). Additionally, a differential modulation of the N400 amplitude by the semantic relatedness between single words in semantic priming experiments is a well-established finding. The N400 component has been consistently observed in response to unrelated target words in the traditional lexical decision task (Anderson & Holcomb, 1995; Bentin et al., 1985; Bentin, 1987; Holcomb, 1988; Holcomb & Anderson, 1993; Holcomb & Neville, 1990; Rossel et al., 2003; Rugg, 1985). The difference in amplitude between responses elicited to unrelated targets compared to related targets has been labelled the N400 semantic priming effect. The present study explored whether a similar N400 semantic priming effect could be found in the ERPs of two year old children. Previous investigations in subjects of comparable age have employed cross–modal priming tasks to examine whether the N400 component could be observed in response to a general semantic incongruity between a presented picture and a word.

In contrast, a purely auditory word-pair priming design manipulating the semantic relation between words was used in the present experiment. This was done in order to see whether the N400-like effect in toddlers also could be shown to be sensitive to the semantic relatedness between single words, a finding that would further point to a functional similarity to the adult N400 response. It was expected to find a difference between the ERPs in the related and unrelated condition, where unrelated target words was hypothesized to elicit an enhanced negativity compared to related target words. The results showed a clear difference between target words that were preceded by unrelated primes and targets that were primed by related words in the 600-800 ms interval after stimulus onset. The difference first appeared at frontal midline sites and reached significance here already in the 400-600 ms interval.

In the 600-800 ms interval, unrelated target words elicited a widely distributed N400-like negativity compared to related targets, however the effect was more pronounced at fronto-central sites and over the left hemisphere. As a control, the initial response to prime words was analyzed. No differences between primes that preceded semantically related and unrelated words were found.

In addition to finding a N400-like semantic priming effect in the 600-800 ms interval, in the 200-400 ms interval related targets were significantly more negative than unrelated targets. Early negative components in a similar time interval, often referred to as N200, have recently been found to be related to word processing in a number of infant and toddler studies (Kooijman, Hagoort, & Cutler, 2005; Mills, Coffey-Corina, & Neville, 1997; Mills, Plunkett, Prat & Schafer, 2005). However, there is presently no agreement as to what kind of language-related process these early components may reflect as they are found in studies with highly divergent experimental designs. Components in these early time windows appear to be modulated by many different features of word stimuli that are not directly linked to word meaning. Therefore, this finding will not be discussed further (see Torkildsen et al. (in press) for a thorough consideration of this early component).

Comparison with earlier studies

The experimental design employed in previous studies of the N400 component in children of comparable ages differs from the current investigation, as they have utilized the classic sentence processing task or cross-modal picture-word priming tasks. Likewise, the earlier event-related potential studies of semantic priming in adults have primarily used visual word presentation in their designs. These differences in design make a direct comparison of the latency and topography of the N400-like effect in the present study to earlier studies difficult.

Only two studies have previously investigated the N400 semantic priming effect with single words solely within the auditory modality (Holcomb & Neville, 1990; Anderson & Holcomb, 1995). Holcomb and Neville (1990) compared the N400 elicited to written word stimuli and auditory word stimuli in the lexical decision task, with semantically unrelated and related targets as stimuli. Relevant to the present study, which used a prime-target SOA of 1200 ms, their experimental design also involved a relatively long prime-target SOA of 1150 ms. This is an important similarity as prime-target SOA is assumed to have marked influence on the type of cognitive mechanism that is engaged during the priming process and thus also on characteristics of the N400 component itself. Note also that the lexical decision task used in the Holcomb and Neville study (1990) involved a decision aspect that was absent in the present study. However, a comparison of results seems defensible, as conscious decision and response-related processes is not generally assumed to be reflected in the N400-component itself (Kutas & Van Petten, 1994).

Holcomb and Neville (1990) found that auditory presented unrelated target words significantly differed from related target words in a negative direction in a very early time interval (from 150 ms after stimulus onset). The difference was long-lasting (to 750 ms) with the most prominent negative peak around 400 ms. The negativity to unrelated target words was widely distributed, however the effect was smaller over frontal and occipital sites and was slightly larger over left temporo-parietal areas.

Latency.

When comparing the present results to the Holcomb and Neville (1990) study an obvious latency difference can be detected. In their experiment a significant divergence between the waveforms in the related and unrelated condition was seen already at 150 ms after stimulus onset, with peak latency of the negativity to unrelated targets at 400 ms. In the present study, a significant difference was established at frontal sites around 400 ms, whereas peak latency was around 600 ms. A difference of 200 ms in peak latency between adult subjects and a group of two year olds is not particularly surprising considering the fact that cross-sectional studies of children at preschool age and older have found that the latency and amplitude of the N400 to decrease linearly with age (Hahne, Eckstein & Friederici, 2004; Juottonen, Revonsuo & Lang,1996). This reduction is commonly explained by an increased facilitation of semantic integration processes with older age (Federmeier et al., 2003). Longer latencies in very young subjects are considered to reflect slower processing of semantic information. In adults, the semantic information activated by the presentation of the prime is processed faster. Most probably children in the present study were slower in exploiting the semantic information provided by the prime.

A direct comparison of latency with earlier investigations in children is unfeasible as these previous studies employed a cross-modal picture priming design. Additionally, in these studies target words differed from the picture primes in that they were either congruent (e.g. dog-dog) or incongruent (e.g. dog-car), investigating the N400 component only as a general semantic incongruity response and not as an index of the semantic relatedness between words (e.g. dog-apple compared to dog-horse). However, the study by Torkildsen et al. (2006) also investigated the N400 as an index of semantic relatedness, as it included both a congruent (e.g. dog-dog), within-category (e.g. dog-mouse) and between-category (e.g. dog-chair) condition. Although not directly comparable, results from Torkildsen et al. (2006) showed that between-category words (analogue to the present study's unrelated condition) elicited a larger negativity than within-category words (analogue to the present study's related condition) in the left frontal brain region in a late time interval (850-950 ms after stimulus onset). Thus, only assessing the difference between the within- and between-category condition in the study by Torkildsen et al. (2006), the N400-like effect in the present study was earlier and more pronounced. The latency difference could be due to differences in stimulus presentation. In some studies of adults the N400 has had shorter peak latency in auditory tasks compared to cross-modal tasks (Holcomb & Neville, 1990; Holcomb & Anderson, 1993). Thus, compared to results in Torkildsen et al. (2006) it is possible that the earlier latency in the present study was an effect of stimulus modality.

Scalp topography.

The N400 like semantic priming effect in the present study had broad distribution with a left-lateralized fronto-central maximum. Generally, the adult N400 semantic priming effect has tended to have a centro-parietal distribution with the effect being more pronounced at right lateral sites. A similar distribution of the N400 semantic incongruity effect is also seen in sentence processing studies (Kutas & Federmeier, 2000).

The earlier event-related potential studies of semantic priming in adults have used visual word presentation in their designs. Holcomb and Neville (1990) investigated the N400 semantic priming effect in both the auditory and visual modality. They reported a wide distribution of the auditory semantic priming effect which was more pronounced on left hemisphere sites. In the visual modality the difference between target types was observed between 300 and 500 ms after stimulus onset. This more short lasting negativity to unrelated targets was widely distributed, yet the effect was larger over right temporo-parietal areas. A left biased distribution of the N400-like effect could be seen in the present study. Only Holcomb and Neville (1990) have established laterality differences on the N400 semantic priming effect according to presentation modality. One study, replicating the original sentence processing experiment of Kutas and Hillyard (1980) in the auditory modality found no significant laterality differences between the visual and auditory presentations of words (McCallum, Farmer & Pocock, 1984).

Stimulus modality might be a reason for the left sided distribution of the effect in the present study, however the restricted quantity of experiments investigating differences between visual and auditory word presentations on the N400 gives reason to withhold such a conclusion.

In addition to a more marked effect over the left hemisphere electrode sites, the N400-like effect was more pronounced on fronto-central sites. A frontal distribution of the N400 component is seldom seen in studies of adults where it rather tends to have centro-parietal pattern (Kutas & Van Petten, 1994). In contrast, some of the previous investigations of the N400 component in children and toddlers have reported anterior distributions of the effect. The experimental design in these studies has involved auditory sentence processing tasks (Silva-Pereyra, Klarman et al., 2005; Silva-Pereyra, Rivera-Gaxiola, et al., 2005), cross-modal picture priming tasks (Friedrich & Friederici, 2004) and word-and picture list presentation tasks (Coch, Maron, Wolf & Holcomb, 2002).

A common explanation of the anterior distribution of the N400 component in equivalent studies is that it overlaps with an age-specific frontally distributed negative component, the Nc, which has been found to be associated with increased attention or processing load in infants and toddlers. The Nc is also elicited in response to surprising and novel events (Nelson & Monk, 2001; Richards, 2003). In relation to the present study, it seems plausible to assume that unrelated target words both capture attention more and give rise to an enhanced processing load compared to related targets. However, it must be noted that there has been no systematic investigations concerning possible variables affecting Nc-amplitude, hence there is no certainty with regard to this explanation.

Friedrich and Friedrici (2004) reported an anterior distribution of the semantic incongruity effect. Apart from a suggested influence by the Nc, they reasoned that the frontal distribution in their experiment could be accounted for in terms of a semantic picture-specific processing factor. In the present study, no picture stimuli were included as a part of the prime-target priming, yet there was an element of picture processing involved, as a filler image, used as attention grabber, initiated each prime-target trial. In the present study filler image offset was more than two seconds prior to the presentation of the targets, and it seems somewhat unlikely that the filler image would affect processing of target words presented two seconds later. Furthermore, it seems doubtful that filler images would have a separate effect on distribution dependent on the type of target word presented in the subsequent trial as they initiated each prime-target trial with random relation to condition type.

In several studies of adults, frontal N400-like negativities have been observed in response to semantically incongruous pictures (Barrett & Rugg, 1990; Federmeier & Kutas, 2001; Holcomb & McPherson, 1994; McPherson & Holcomb, 1999; West & Holcomb, 2002). Furthermore, such negativities have been seen in response to concrete nouns which are words referring to objects that is easy to visualize (Holcomb, Kounios, Anderson, & West, 1999; West & Holcomb, 2000). The anterior negativities seen to both pictures and concrete nouns have been suggested to index image-mediated semantic processing that is functionally akin to the processing of semantic information as indexed by the classic N400, but most likely maintained by different brain regions (West & Holcomb, 2002).

In the extended N400 literature pictures and concrete nouns are proposed to have a more direct access route to their semantic representations, which consequently lead to a frontal shift in the distribution of the effect (Holcomb et al., 1999; West & Holcomb, 2000; West & Holcomb, 2002). These claims may seem weakly theoretically motivated as there is seldom given an elaborate account of the brain mechanism behind the direct route. However, the idea that pictorial and spoken stimuli may access a common semantic memory system is a familiar assumption in the behavioural literature (Ellis & Young, 1989; Kroll & Potter, 1984).

Word stimuli in the present experiment consisted of concrete nouns. As previously mentioned, word stimuli consisting of concrete nouns have been suggested to elicit activity in an image-based conceptual system (West & Holcomb, 2000). In a study of adults, West and Holcomb (2002) proposed that both pictures and concrete words access an amodal semantic system that process both image-based and abstract conceptual information.

In a study were both concrete words and pictures were presented in separate lists to school-aged children, both types of targets elicited identical looking anterior distributed negative waves that peaked around 450 ms after stimulus onset (Coch et al., 2002). Coch et al. (2002) suggested that the similarity could reflect activity in a common amodal semantic system.

The word stimuli employed in the present study were presented in the auditory modality. In the behavioural literature auditory presentations of prime and target stimuli are thought to give purer semantic priming effects than visual word stimuli as the processing of auditory stimuli avoids orthographic analysis and grapheme to phoneme conversion. Some studies have reported larger semantic priming effects using auditory presentations of word stimuli (Lucas, 2000). One proposed explanation for the discrepant findings across visual and auditory word presentations in the behavioural literature has been that auditory primes have "preferred access" to their semantic representations, similar to a direct route to semantics attributed to pictorial stimuli (Hutchinson, 2003). In some auditory sentence processing studies with older children a similar line of reasoning is found in the N400 literature (Silva-Pereyra, Klarman, et al., 2005; Silva-Pereyra, Rivera-Gaxiola, et al., 2005). Silva-Pereyra, Rivera-Gaxiola, et al. (2005) observed in both 36 and 48 month old children that semantic violations of the preceding sentence fragment gave rise to a large negative N400 semantic incongruity effect over anterior brain regions, peaking around 500 and ending at 800 ms. They considered this a reflection of activity in anterior concept-relevant brain areas, thus echoing the suggestions of activity in a common semantic system.
Although an explanation of the frontal distribution of the effect in the present study in terms of the same mechanism is speculative, it seems important to at least note that the stimuli used in the present experiment were auditory-presented concrete basic level nouns.

Priming mechanism: automatic versus controlled processing

As mentioned in the introduction adult ERP-studies usually discuss whether observed semantic priming effects can be explained by automatic or controlled processing mechanisms. In adults the answer to this question is decided by looking at specific features of the experimental design. For instance, one would conclude that a semantic priming effect was realized by a controlled processing mechanism if the design involved a high proportion of related prime-target pairs and a SOA above 400 ms.

Considering the experimental design of the present study the observed N400–like semantic priming effect should, if it was conducted in adults, be seen as realized by a controlled processing mechanism. Two main features of the experimental design, a high proportion of related prime-target pairs (50-50) and the long prime-target SOA (1200 ms), could clearly be said to induce either expectancy-based or attentional priming, as the large proportion of related targets could induce the subjects to actively expect the target item based upon the meaning of the prime word and the long SOA would give the opportunity to use conscious attentional resources in the processing of the prime-target relationship. However, the discussion of automatic versus controlled processing mechanisms is based on findings from visual word priming studies in adult subjects. The division is not directly applicable to findings from children as young as 24 months, since controlled processing mechanisms are generally not assumed to be fully developed in this age group (Diamond, 2002). Prime-target proportion and SOA most certainly have different effects on processing in adults and toddlers. Toddlers have a restricted vocabulary and consequently a limited set of related meanings stored in memory. Furthermore, very young children are known to process information at a slower rate than adults (Kail, 1988; 1991). Therefore, it is highly possible that the N400-like priming effect of the present study is the result of an automatic process.

Priming relation: semantic versus associative priming
Results established that unrelated target words elicited an enhanced negativity compared to related targets in the 6-800 ms interval. Also, the modulation of the N400-like effect was clearly caused by the relation to the prior presented prime such that related primes facilitated processing of related targets. As mentioned in the introduction, there is a question whether semantic priming effects are truly semantic or simply a reflection of associative co-occurrences across words within a language, or both. Nevertheless, teasing apart semantic influences from associative influences is difficult because these relationships typically are correlated (Balota, 1994; Schwanenfugel, 1991). The question of associative influences on modulations of the N400 component might in principle be raised as a potential confounding dimension in any study reporting semantic priming effects. In many semantic priming studies prime-target relation is of a categorical associative type (e.g. cat-mouse) where there simultaneously is a strong associative and categorical relation between the related prime and target. In contrast, pairs in the related condition in the present study were solely selected on the basis of taxonomic category membership (e.g. horse-bird). There were taken no measures to control for associative relations of words in the selection of stimulus words, partly because frequency counts of associative co-occurrences of words directed to children in the relevant age group is lacking. The grouping criterion for the nouns was semantic category relation, and it seems unlikely that the priming effect found in the present study could purely be due to associative relations between words. Although associative relations probably have contributed to priming in some related trials, word pairs were selected on criteria of category relatedness, overall giving reason to call the N400-like priming effect observed in the present study a semantic priming effect.

As stated previously, a semantic priming effect may arise either from word representations on a semantically organized lexical level or it may be produced from overlap of the semantic features of concepts on a conceptual level. Alternatively, the priming effect could arise from associative connections on the lexical level due to co-occurrences between words or on the conceptual level due to associative co-occurrences of the objects that the words denote.

Stimuli in the present study consisted of auditory-presented single words, where no pictures or sentence fragments were a part of the priming procedure. This is in contrast to the earlier cross-modal studies in children of comparable age (Friedrich & Friederici, 2004, 2005a, 2005b, 2005c; Torkildsen et al., 2006). In the earlier studies the N400 semantic priming effect theoretically must be said to reflect either semantic or associative processes partly mediated on a conceptual level as cross-modal tasks were employed. In contrast, in the present experiment, the N400-like effect might reflect processes solely on the lexical level. However, the unimodal design may also be said to give a direct access to representations on a higher conceptual level. Empirically, on what level the priming occurred in the present experiment is an open question.

Non-semantic influences

The N400 response to single words in adults has been found to be modulated by non-semantic factors like word frequency and word repetition. In some studies (Van Petten & Kutas, 1990; Rugg, 1990) word frequency, defined as the frequency with which a word occurs in language (decided by normative frequency counts of written sources) has been shown to modulate the N400 amplitude, such that the response to low frequency words are more negative than the response seen to high frequency words. This effect has largely been accounted for in terms of the relative ease with which words of different frequencies activate their stored lexical representations (Balota, 1994; Tabossi, 1991). Results from other studies (Holcomb et al., 2005; Raposo et al., 2006; Van Petten et al., 1991) have established that the word repetition effect, which refers to the greater processing efficiency seen for repeated words, is a potent modulator of the N400 component, such that repetitions of a word lead to a reduced N400 to those words as compared to unrepeated words. These factors are probably not plausible alternative explanations of the effect found in the present study, as none of them varied with experimental condition. Although there was no explicit attempt made to choose frequency-matched word stimuli in the present experiment (which has not been done in any of the prior studies of children in this age group), it would seem implausible to assume that there was a consistent difference between the words used in the related and unrelated condition in terms of frequency, as the initial set of stimuli was randomly assigned to each of the two conditions and used both as primes and targets. The same argument applies to a possible effect of repetition. Further bolstering this argument is the fact that the initial responses to prime words was similar across conditions, such that the difference between the target words seems to be dependent on the semantic relationship to the preceding prime word.

Conclusion

The present study investigated whether the N400 component in toddlers could be shown to be sensitive to the semantic relatedness between single words in a modified electrophysiological version of the behavioural lexical decision task. Stimuli consisted of auditory presented basic level nouns presented in prime-target pairs in two conditions, where words in the related condition belonged to the same superordinate category (e.g. cat-horse) and in the unrelated condition belonged to a different superordinate category (e.g. cat-chair). Results revealed a clear difference between target words that were preceded by unrelated primes and targets that were primed by related words in the 600-800 ms interval after stimulus onset. The negative polarity of the waveform, the direction of the difference (unrelated target words more negative than related target words) and the fact that the differential response to target words appeared to be dependent on the relation to the prior presented prime, suggest that the difference between the target types was an effect of semantic priming and is similar to the previously reported N400 semantic priming effect found in adults.

Previous investigations of children of comparable age have shown that the N400 component can be elicited in response to incongruous words in sentence processing experiments and in cross-modal priming experiments. In these studies the N400 was elicited as a result of a general semantic anomaly between the presented sentence or picture and target word. In adults the N400 has been shown to be modulated by both semantic incongruence and semantic relatedness between words. So far, a semantic relatedness effect on the N400 has not been shown in toddlers. While the N400 in previous toddler studies has reflected detection of semantic incongruity, the N400-like effect in the present study probably reflects some awareness of the degree of semantic relatedness between words. The results give no information as to whether children have acquired superordinate terms (e.g. animal) or if there is a hierarchical organization of words or concepts at this age. However, as a manipulation of the semantic relatedness between subordinate basic-level nouns can be demonstrated, further studies should modify stimuli to include category instance relations (e.g. animal-horse) to investigate these questions.

The N400-like effect in the present study had a somewhat more frontal distribution compared to results from most of the cross-modal experiments previously conducted in toddlers. The frontal distribution could tentatively be suggested to relate to both the choice of stimulus modality (auditory) and the type of words presented (concrete nouns). Similar frontal distributions of the N400 component for concrete words and pictures found in both adults and older children has been suggested to indicate joint access to an amodal semantic system. A further exploration of the N400 scalp distribution in an experiment comparing priming effects in an pure auditory condition with a pure picture-presentation condition or a cross-modal condition within the same set of subjects in the relevant age group, might point to whether this explanation also hold for the results in the present study.

The establishment of an N400-like semantic priming effect in the present experiment indicates that priming studies can be used as a functional tool in investigations of word meaning in very young children and provides an opportunity to investigate semantic memory at a very early stage in development. In addition, as the method can be used on both children and adults it is possible to compare and describe semantic priming effects across different ages.

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