Cortical N400-Potentials Generated by Adults in Response to Semantic Incongruities

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Abstract

Eight adult participants were investigated in a pre-experiment for the future assessment of semantic N400 effects in children. The materials were words presented in semantically incongruent vs. congruent picture contexts. For example, the word duck was played while a picture of a tree was shown in the incongruent test condition vs. the word duck was played while a picture of a duck was shown in the congruent test condition. A larger N400 effect was expected in response to the incongruent audio-visual pairings. The results showed in time extended peak-to-peak differences between congruent and incongruent audio-visual pairings at the centroparietal, parietal and parieto-occipital recording sites. This study was performed to validate the current materials to be used to answer questions on appearance of the N400 component in children.

1 Introduction

This pre-experiment on cortical responses to semantic incongruities in adults was performed within the project called "Early Development of Hemispheric Specialization for Speech Processing"[1]. The main aim of the project is to study establishment of language-related specialization in the brain and its specific links to different phases of language development early in life. Two EEG-studies (electroencephalography) are planned to be performed within the projocet: (1) Swedish materials, materials from a foreing language and "rotated speech" will be used to study lateralization of speech and its prosodic components in a developmental perspective in young children, and (2) Semantically incongruent audio-visual (AV) materials will be used to study the development of cortical activites that are likely to mediate semantic processing, as revealed by the so called N400 incongruity effect.

It is our goal that the basic research data collected from typically developing children will in future be applicable in establishing potential early signs of deviant language development in children with cognitive disorders, such as autism spectrum discorders (ASD).

Thus, neurophysiological experiments with adults were performed as a first step to reach the project goals. The rationale for investigating N400-potentials in response to semantic incongruitites across the AV domains in adults is to verify use of ERPs in response to the current materials. Also these data function as a baseline against which results from typically, as well as atypically developing children may be tested.

The adults in the current study were tested on auditory (A) and visual (V) materials in two test conditions: one using congruent, and the other using incongruent A-V pairings of objects.

2 Background

Emergence of linguistically induced semantic representations is known to appear during the second year of life (Bates et al., 1994). The child naming objects in its environment is naturally the most obvious demonstration of an indivual having conceptual compentence. However, the mechanisms involved in integration of meaning at a higher level are not well understood nor easily observed in children. These processes are presumably best investigated with help of imaging studies to complement results from behavioural studies.

Event-related potentials (ERPs) are a series of positive and negative voltage deflections in the ongoing EEG that are time-locked to sensory, motor, or cognitive events. The ERP component called N400 (N indicating that the peak is negative at around 400ms after the stimulus) is presumably the best known evoked response potential that is sensitive to variations in the semantic contents of words and sentences

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(Bentin & McCarthy, 1994; Hagoort & Brown, 2002; Kutas, 1997). The N400 effect functions in the way that presentation of A-V pairings induce it in general, but the effect is strongest in response to incongruent materials (i.e. when the word presented is semantically incongruent with the picture).

What is known about the N400 effect in adults and children? First, semantically anomalous, relative to well-formed sentences produce a larger N400 effect both in children and adults (N=130, 5 to 26 years) (Holcomb, Coffey, & Neville, 1992). Yet N400 activation in younger children (5 to 14 years) is widely distributed, including the midline frontal och frontalcentral recording sites, relative to activation in adults and older children where it is limited to posterior areas only. Second, the N400 amplitude may be significantly higher for children (5 to 13 years) relative to adults. In addition, significant effects for delayed peak latency and extended duration of the effect in children are found (Atchley et al., 2006; Friederici & Hahne, 2004; Juottonen, Revonsuo, & Lang, 1996). In young infants, semantic processing mechanisms indexed by N400 are suggested to be present at 14 and 19 months of age (Friedrich & Friederici, 2004; Friedrich & Friederici, 2005).

2.1 The aim of the current study

The present study investigates adult N400-response using a child-adapted experiment design, creating a baseline for future studies. A picture-word paradigm with coloured pictures of familiar objects and slowly spoken words, either naming the object in the picture (A-V congruent condition) or naming another object (A-V incongruent condition) is used. The latter condition is expected to elicit the most significant N400-responses (see Figure 1). The distribution of N400 is expected to be maximal at posterior midline scalp locations, in specific the centroparietal (CPz), parietal (Pz), and parieto-occipital (POz) sites.

3 Method

The participants were 8 native speakers of Swedish (3 male and 5 female). Mean age was 32 years, ranging from 21 to 55 years. Seven of the participants were right-handed and all of them reported normal hearing. One of the participants was familiar with the materials and the research question of the study. The stimuli consisted of cartoon-like pictures of objects, and recordings of the labels (words) of the objects (figure 1).

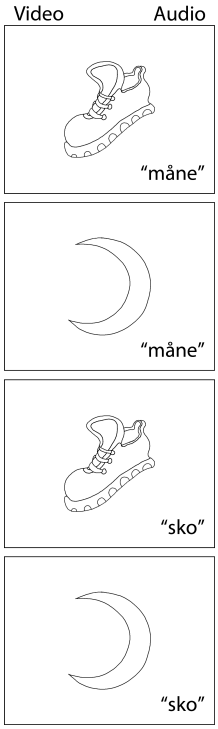

Figure 1. Examples of experiment trials. The word was uttered 1000 ms after the picture. The two middle trials belong to the congruent condition (audio and video match) and the top and bottom trials belong to the incongruent condition (audio and video do not match). Trials were presented in random order.

In earch trial, the picture was first presented, and after 1000 ms, the label was presented. In the congruent condition the picture of the object was paired with the correct label. In the incongruent condition, each picture of an object was paired with an incorrect label, controlled so that the correct label for the image and the incorrect label used differed in their first phonemes, with regards to articulation-type and voicing. A total of 48 object labels were used in the study, each presented once in the congruent condition and once in the incongruent condition, resulting in a total of 98 trials. The trials were presented in random order. The words were chosen from the Swedish Early Communicative Developmental Inventory (SECDI; Eriksson & Berglund, 1996) for compatibility with future infant studies, in which age-appropriate words will be chosen. The words were read by a female native speaker of Swedish and recorded in an anechoic chamber. The materials were digitally saved to a hard drive, segmented and manually matched for

loudness. Single word duration ranged from 526 to 1178 ms.

A net of electrodes was placed on the participant's head, and stimuli were presented using a computer screen and loudspeakers. Participants were asked to listen attentively to the stimuli, but were given no explicit task. The experiment session lasted approximately 14 min.

3.1 Data preparation

Net Station tools cleaned the data with a band pass filter from 0.3–30 Hz noise, segmented the responses into 96 segments of 1100 ms each (100 baseline before stimuli onset, 1000 ms after stimuli onset), and removed unusable channels and segments (*e.g.* eye blinks) before collating segment averages across stimuli conditions, and referencing the EEG-voltage measurements to a baseline prior to stimuli onset.

4 Results

Two participants (N=2) were excluded from the analysis based on the characteristic brain wave response, known as P300, often elicited by an infrequent, task-relevant stimulus. The P300 effect is present for participants number 3 and 6 illustrated by the upgoing thin line corresponding to semantically incongruent trials towards the end of the wave in Figure 2.

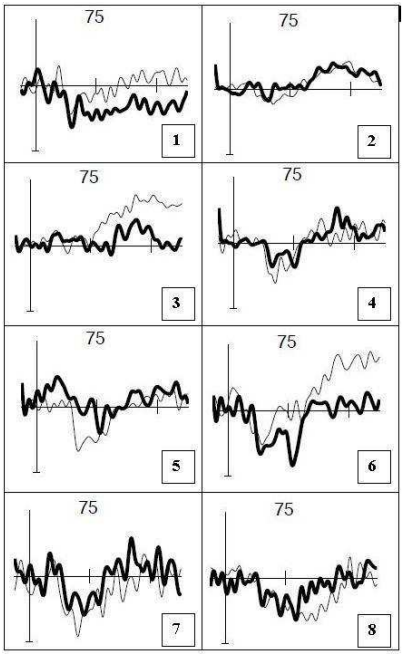

Figure 2. The P300 effect, considered to reflect response to non-standard items intermixed with high-probability items, is illustrated by the up-going thin line for participant number 3 and 6.

Figure 3 displays average ERPs elicited by congruent (thick lines) *vs.* incongruent (thin lines) trials for the participants (N=6) included in the analyses. The time period begins at 0 ms corresponding to the stimulus onset and ends 1000 ms post-stimulus. Waveforms for five electrode sites are depicted (Fz=11, FCz=6, CPz=55, Pz=62 and POz=72) to highlight the scalp distributions for the N400 waveforms. The incoruity effect, illustrated by the diverging wave-forms, was most prominent at the cenroparietal (CPz=55), parietal (Pz=62), and parieto-occipital (POz=72) sites. The incongruity effect was present approximately within 300 to 800 ms at the CPz (55), and within 200 to 800 ms at the Pz (62) and POz (72).

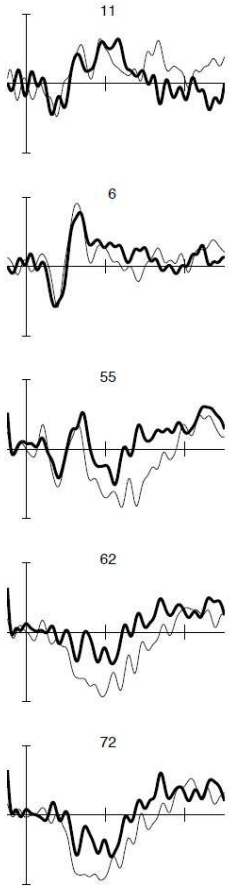

Figure 3. Averaged ERP wave-forms generated by the congruent (thick lines) vs. incongruent (thin lines). The short vertical marks along the time line correspond to 400 ms and 800 ms post stimulus. The N400 effect is most prominent (illustrated by the diverging wave-forms) within 300 to 800 ms at the CPz=55, and within 200 to 800 ms at the Pz=62 and POz=72 eclectrodes.

5 Discussion

As shown in previous studies, adult participants (N=6 of total N=8) in the current study elicited a N400 effect in response to semantic incongruities at the midline posterior scalp locations.

Two participants were excluded from the analysis based on a prominent P300 effect that was suspected to cancel out their N400 incongruity effect. We used this rejection criterion because P300 is thought to reflect processes involved in stimulus categorization. For example, P300 is often elicited in response to low-probability target items that are inter-mixed with high-probability non-target (or "standard") items. In the current study the 48 pictures of objects shown once in the congruent condition and once in the incongruent condition presented in random order. Despite of the fact that the congruent vs. incongruent trials were presentend in random order, we suspect that subsequent presentations of "standard" congruent stimuli might for the participants in question have caused a P300 effect in response to seemingly novel low-probability incongruent trials. In the current experiment participants were asked to listen attentively to the stimuli, but they were not given any explicit task. In future studies P300 effect is presumably best eliminated by giving participants a pseudo task to perform (such as to press a button in response to every fifth trial).

The current study is a pre-experiment on eight adult participants to study N400 effect in children. Therefore it is premature to speculate on implications of the results given the obvious need for replication and extension of the current research. Also, additional analyses of cortical responses *within* the incongruent condition are to be performed on animate *vs.* inanimate objects. However, if these results prove robust then they could be very informative and function as a baseline for N400 studies in children with typical language development *vs.* in children with ASD.

Typically developing infants are expected to have a higer N400 component amplitude, more delayed component latency, and more widely distributed scalp distribution relative to adults. The onset of speech and other linguistic milestones are typically delayed in children with ASD. Autism is of particular interest in this project because it offers the opportunity of testing a theoretical perspective proposing that correlated sensory information is the very key to the development of linguistic referential function. The activation pattern found in typically developing children is not expected to show as clearly (if at all) in children with ASD.

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