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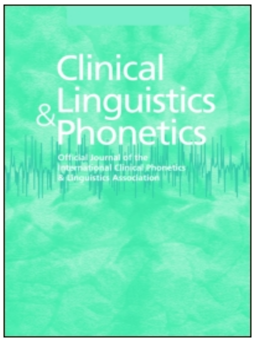

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N400 and short speech stimuli

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ABSTRACT

In some children who have cochlear implants (CI), the expected speech-language outcome is not achieved despite fulfilment of requirements for its successful use. This may be attributed to processing difficulties at higher levels of the auditory pathway. The aim of this study was to investigate the processing of speech stimuli at the auditory-cortex level in 20 children aged 8 to 10 years who have a hearing impairment and have been using cochlear implants, by means of cortical auditory evoked potentials (CAEP). The children were divided into two groups, depending on the outcome: 10 successful implant users and 10 unsuccessful implant users, whose speech-language development has not progressed as expected. The control group comprised of 10 age-matched children with typical hearing and speech-language development. Two double consonant +vowel syllables (CVCV) were used as stimuli, presented in an oddball paradigm that required the subjects to react consciously. Latencies and amplitudes of CAEP waves were measured. In addition to the waves that typically occur in CAEP and reflect auditory processing at the level of the auditory cortex, N400 wave (associated with semantic processing) was recorded in the normally hearing group and successful CI users, but not in the unsuccessful CI users. Additionally, successful CI users and controls had comparable latencies of the P300 wave (preceding the N400) as well. Although P300 and N400 reflect two processes, they are related so that if P300 does not reach the expected amplitude and latency, neither will N400.

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Introduction

Several factors have been shown to affect the outcome of cochlear implant (CI) usage: age at implantation (Archbold et al., 2008; Sharma, Dorman, & Kral, 2005; Sharma, Dorman, & Spahr, 2002a, 2002b; Sharma, Gilley, Dorman, & Baldwin, 2007; Vlahović & Šindija, 2004), post-implant hearing level, duration of speech and hearing therapy after implantation (Paškvalin et al., 2005) and status of the vestibular system (Mijić-Munivrana, 1994), so that earlier implantation, lower post-implant hearing threshold, longer therapy and intact vestibular system are prerequisites for successful CI use. However, some children do not reach satisfactory levels of auditory functioning even if all these requirements have been met. This may be attributed to hearing disorders at higher levels of the auditory pathway. In this respect, they exhibit similar auditory processing difficulties as children with typical hearing but with specific language impairment (SLI). It is known that some

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children with SLI have difficulties in the perception and discrimination of short sounds that follow each other in short time intervals (Bishop & McArthur, 2004), and that some have difficulties in the discrimination of frequency characteristics of sound, due to impaired temporal processing of acoustic stimuli (Bishop, Hardiman, Uwer, & von Suchodoletz, 2007).

Cognitive auditory evoked potentials (CAEPs) have been used as the method of choice for studying the functioning of the auditory cortex and other structures which are crucial for the cognitive processing of auditory stimuli because of their good temporal resolution, non-invasiveness, and suitability for use in children with cochlear implants. They provide valuable data on brain processes involved in the perception of loudness, pitch, and source of sound detection. Exogenous components (P1, N1, and P2) reflect the activity of the primary auditory cortex while endogenous components N2 and P3 reflect the activity of higher cognitive processes and may be useful for targeted treatment (Stevens, Fanning, Coch, Sanders, & Neville, 2008). They provide a window on the earliest stages of processing in the auditory cortex. The P300 (P3) is an event-related potential that occurs approximately 300 ms after stimulus onset and reflects the cognitive processes underlying the discrimination of dissimilar sensory stimuli. This is crucial in the clinical assessment of speech discrimination ability because successful speech perception relies on the discrimination between fine acoustic features in speech (Sharma, Kraus, McGee, & Nicol, 1997). CAEP-based studies of CI implant users whose hearing rehabilitation did not progress as expected recorded longer latencies and reduced amplitudes of P3. This correlation suggests that the P3 component is a good indicator of acoustical-phonological processing (Henkin, Kileny, Hildesheimer, & Kishon-Rabin, 2008; Henkin, Tetin-Schneider, Hildesheimer, & Kishon-Rabin, 2009).

In studies using non-specific event-related potentials (ERPs), in addition to P300, N400 component has been identified as manifesting the processing of deviant and unexpected events. The P300 is not modality specific: it can be elicited by visual events (i.e., flashes, written words, pictures), tones (e.g., Squires, Wickens, Squires, & Donchin, 1976; as cited in Duncan et al., 2009), speech (e.g., Berlad, & Pratt, 1995; Friedman, Simson, Ritter, & Rapin, 1975; Geal-Dor, Kamenir, & Babkoff, 2005; as cited in Duncan et al., 2009), tactile stimuli, and even by the unexpected absence of a stimulus (Sutton, Tueting, Zubin, & John, 1967; as cited in Polich, 2007). Research into the P300 component during the past several decades indicates that this component reflects processes related to deviant stimuli. However, when the deviant stimulus is a word that violates context-dependent expectations, a negative component is recorded with a latency of approximately 400 ms. The amplitude of this wave is affected by context violation in paragraphs (van Berkum, Haghoort, & Brown, 1999), sentences (Kutas, & Hillyard, 1980a, 1980b, 1984; as cited in Duncan et al., 2009) and even in pairs of words when the first word of the pair sets the context (Bentin, McCarthy, & Wood, 1985; Holcomb, & Neville, 1990; Kutas, & Van Petten, 1988; as cited in Duncan et al., 2009). It was found that the N400 amplitude is correlated with the degree of difficulty in accessing semantic representations in long-term memory (Kutas & Federmeier, 2000) and there is general agreement that N400 is closely related to semantic and contextual processing. Components P300 and N400 represent two different processes: a reaction to stimulus change, i.e. to a change in the environment, and a reaction to language processing (Arbel, Spencer, & Donchin, 2011).

The aim of the study was to investigate whether a short speech segment (double syllable), presented in a classical odd-ball paradigm, can elicit (in addition to the standard P300 wave) the N400 wave, associated with linguistic (semantic) processing, and to provide some guidelines for explaining this possibility.

Method

Participants

The study involved two groups of children with hearing impairment and fitted with CI (unilaterally), aged between 8 and 10 years, and a control group of age-matched children with normal hearing threshold. All children with CI had unaided 3-frequency pure-tone audiometry (PTA) thresholds > 95 dB and were diagnosed with *Anacusis perceptiva bilateralis*. With implant in place, their hearing level was between 15 and 30 dB (3-frequency PTA). Based on the capacity of intelligibility field (calculated as the ratio of the area spanned by the SA curve to the typical SA) the CI children were divided into two groups: Group S2 consisted of 10 CI children whose capacity-of-intelligibility-field score was lower than 80%. All were attending the elementary school within the Suvag Polyclinic for rehabilitation of speech and hearing (Zagreb, Croatia). Group S3 comprised 10 CI children whose capacity-of-intelligibility-field score was between 80 and 100%. All participants in this group were mainstreamed in elementary schools and visited Suvag Polyclinic for processor adjustments.

Any neurological, psychological, audiological, and motor disorders were excluded. The lower age limit was set at 8 years because the testing requires the subjects to be still and awake. Gender was not considered a relevant variable, as it does not influence the response to auditory stimuli.

The 10 age-matched controls (group S1) were normally-hearing children with typical speech and language development, and normal neurological status. The study was approved by the Polyclinic's Ethics Committee and parental consent was obtained for all children.

Procedure

Researchers measured the responses, latencies, and amplitudes of P1, N1, P2, N2, and P3 waves, which are an acceptable measure of the cognitive processing of auditory target stimuli. The recording was performed on a 32-channel Neuroscan system (Compumedics Neuroscan, El Paso, TX, USA), using an electrode cap with a set of electrodes arranged according to the International 10–20 electrode positioning system. The reference electrodes were linked together and placed over the left and right mastoid processes. All electrode impedances were less than 5 kΩ. During the recording, a child fitted with a headset lay comfortably on a bed with eyes closed in a dark, quiet room. ERP recording was done according to the auditory oddball paradigm consisting of two kinds of stimuli: target (rare) and non-target (frequent). The participants were told to ignore the non-target and to press a keyboard button with the index finger of their dominant hand as soon the target stimuli is recognized. Stimuli were presented by means of a loudspeaker (Trust 460P soundforce) placed 20 cm from the head of CI participant on the CI side and 20 cm in front of control participants. The stimulus intensity was 70 dB SPL at the input to the CI microphone or 70 dB SPL at the output from a loudspeaker. It was measured with SPL meter ("Digital-Display Sound-Level Meter", Model: 33–2055). Testing took a little over 45 min per participant, including preparation and recording (Munivrana & Mildner, 2013).

Stimuli

The stimuli were double syllables *ka-ka* (non-target, frequent) and *te-te* (target, rare). Both double syllables consisted of consonants and vowels typical of Croatian language (Guberina & Asp, 1981; Munivrana & Mildner, 2013). The duration of each double syllable was 370 ms, and the interval between two syllables was 30 ms. Researchers used double-syllable CV stimuli rather than single syllables because of their complexity, with the aim of making them as speech-like as possible. These stimuli were tested in comparison with single-syllable CV and there were no double/overlapping CAEP responses.

For each ERP recording, the intensity of every stimulus was equal and set to 70 dB. The non-target stimulus (*ka-ka*) was frequently repeated, whereas the target (*te-te*) appeared rarely and randomly. The ratio of frequent to rare stimuli was 4:1. The interstimulus interval (ISI) was set to 2.5 s with 10% of the variability. The actual number of target stimuli was slightly above 50 because the averaging procedure stops after 50 artefact-free responses have been collected. The artefact rejection level was ±100 µV. Therefore, non-target stimuli were presented more than 200 times. The analysis time was set to 1100 ms including 100 ms of the pre-stimulus interval for baseline correction. The amplifier gain was set to 40 000, the sampling rate at 1 kHz and EEG was processed with band-pass filters ranging from 0.1 to 30 Hz. EEG sequences distorted by ocular movements and blinking were automatically rejected if their amplitudes exceeded ±100 µV of artefact rejection level. Averaging was performed on-line and off-line if too many ocular artefacts were detected. In such cases, the Neuroscan ocular rejection artefact algorithm was applied. Also, ocular algorithm was applied to all participants in off-line averaging. The responses to target and non-target stimuli were averaged. Evoked potential latencies and amplitudes were measured. Peak amplitudes at Cz electrode were measured relative to the pre-stimulus baseline (Munivrana & Mildner, 2013).

Statistics

Saved EEG data were averaged by NeuroScan software and the obtained values were analysed by descriptive statistics, Shapiro-Wilk test, Levene's test and two post hoc tests: Games-Howell and Tukey's. Confidence level was set to 95%. Data were analysed using Statistical Package for the Social Sciences, ver. 15.0 (SPSS Inc., Chicago, IL, USA).

Results

The cortical auditory evoked potentials (CAEPs) obtained for all three groups of participants are shown in Figure 1. Even superficial inspection of the curves, particularly of the N400 wave, reveals that the unsuccessful CI users (group S2) have longer latencies and smaller amplitudes than successful CI users (group S3) or controls (group S1).

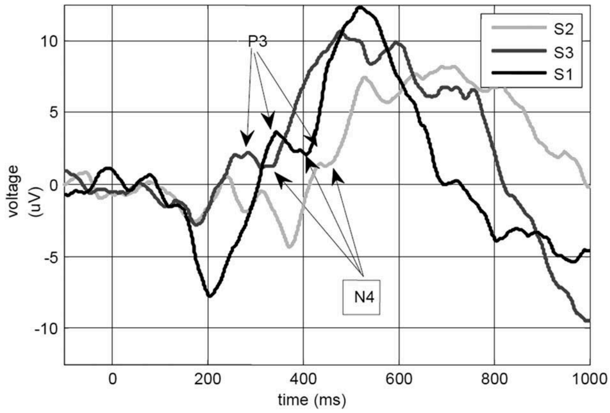

Figure 1. CAEP for target stimulus.

Since Shapiro-Wilk test did not indicate statistically significant departure of latency distribution from normal distribution in any of the groups, mean and standard deviation were used as measures of central tendency and variability, and the groups were compared using analysis of variance (Table 1).

There was a statistically significant difference in latency among the three groups of children, so post hoc test was performed for additional comparison. Since there was large variability of results in the group of unsuccessful CI users (S2), and Levene's test indicated that groups variances were heterogeneous, $F(2, 27) = 5.20$, $p = .012$, groups were compared using Games-Howell post hoc test. Unsuccessful CI users (S2) had statistically significantly longer latency compared to the typically developing group (S1) ($p = .017$) and compared to S3, group of successful CI users ($p = .007$). The difference between successful cochlear implant users (S3) and those with typical development (S1) was not statistically significant ($p = .730$).

There was no statistically significant departure of amplitude distribution from a normal distribution, so mean and standard deviation were used as measures of central tendency and variability, and groups were compared using analysis of variance (Table 2).

There was a statistically significant difference in amplitude among the three groups of children, so post hoc test was performed for additional comparison. Since Levene's test did not indicate that groups variances were heterogeneous, $F(2, 27) = 1.51$, $p = .240$, groups were

Table 1. Latencies in all studied groups.

Group	*M*	*SD*	*F*(2, 27)	*p*
S1 (controls)	404.8	43.04	10.29	< 0.001
S2 (unsuccessful CI users)	500.2	83.47		
S3 (successful CI users)	390.8	38.47		

Table 2. Amplitudes in all studied groups.

Group	*M*	*SD*	*F*(2, 27)	*p*
S1 (controls)	6.5	4.06	3.93	0.032
S2 (unsuccessful CI users)	3.0	2.46		
S3 (successful CI users)	8.0	5.22		

compared using Tukey's post hoc test. Unsuccessful CI users (S2) had a statistically significantly smaller amplitude compared to the group of successful CI users (S3) (p = .029). Although the group of typically developing children (S1) also had larger amplitude compared to unsuccessful CI users (S2), the difference did not reach statistical significance (p = .154). The difference between successful cochlear implant users (S3) and those with typical development (S1) was not statistically significant (p = .698).

Discussion

The analysis of N400 latencies and amplitudes revealed statistically significant differences among the studied groups: unsuccessful CI users (S2) exhibited significantly longer latencies and smaller amplitudes compared to S3 (successful CI users) and S1 (controls). In fact, the N400 amplitudes recorded in the S2 group are so small that one can hardly speak of any wave occurrence at all (Figure 1). The results obtained in a study of waves that precede the N400 (P1, N1, P2, N2 and P3) indicate that these S2's latencies and amplitudes, as well as the time and accuracy of their responses to target stimuli, are significantly different from successful CI users and typical hearing peers (Munivrana, 2011). The two double syllables used in this study, *ka-ka* and *te-te* are speech-like material because they comprise legitimate CV combinations, but they cannot be considered actual words because they lack word stress and are pronounced as two equal syllables. However, in Croatian children's vocabulary both combinations are associated with notions that they are familiar with. Word *káka* refers to something dirty, not for use, to be avoided and to bowel movement. Since the N400 wave reflects linguistic and semantic processing, and according to some authors can be elicited even with two words if one of them constitutes a strong enough context that is violated by the occurrence of other one (e.g., Bentin, McCarthy, & Wood, 1985; Holcomb, & Neville, 1990; Kutas, & Van Petten, 1988; as cited in Arbel et al., 2011), it is apparent that the double syllable *ka-ka* has been recognized as the word *káka*. The other double stimulus, *te-te*, is associated with the word *téte* that refers to aunts, kindergarten teachers and any unfamiliar females. In other words, both stimuli may be attributed meaning. Interestingly, the children in groups S1 and S3 were processing the double syllable stimuli semantically, in other words, they were looking for meaning, which reflects the preference for top-down processing in familiar language stimuli, i.e., the need to make sense of every piece of communication, no matter how small the segment. The rationale for using double syllables in this study was to achieve stimulus complexity. This elicited two waves that belong to two different processes: P300 and N400 (Kutas, & Hillyard, 1980a; as cited in Arbel et al., 2011). The former is a reaction to stimulus change (general cognitive processing), and the latter is specific to language processing. Successful CI users and controls alike had comparable latencies and amplitudes of both P300 and N400 waves, which suggests that the two processes work closely together and both reflect reactions to unexpected events.

Conclusion

This study has shown that a short speech stimulus presented in an oddball paradigm can elicit both the P300 and the N400 waves. Although they reflect two processes, they are related: P300 precedes N400 and if P300 does not reach the expected latency and amplitude neither will N400. In other words, linguistic processing follows general cognitive processing and is related to it, and this may be an indication that they rely on common resources. The small number of participants precludes any wider generalization, but the results may be useful in planning speech and language therapy by suggesting the importance of increasing working memory capacity. It also has diagnostic value because it provides data on both P300 and N400.

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Disclosure Statement

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