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An objective auditory measure to assess speech recognition in adult cochlear implant users

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HIGHLIGHTS

- Cochlear implant (CI) users who performed well on the speech recognition task have similar auditory evoked potentials to those of the normal hearing participants.
- CI users who performed more poorly on the speech recognition task present a significantly abnormal auditory evoked potentials compared to the better performers and the normal hearing participants.
- The mismatch negativity auditory evoked potential can be used to assess speech recognition in CI users.

ABSTRACT

Objective: To verify if a mismatch negativity (MMN) paradigm based on speech syllables can differentiate between good and poorer cochlear implant (CI) users on a speech recognition task.
Methods: Twenty adults with a CI and 11 normal hearing adults participated in the study. Based on a speech recognition test, ten CI users were classified as good performers and ten as poor performers. We measured the MMN with /da/ as the standard stimulus and /ba/ and /ga/ as the deviants. Separate analyses were conducted on the amplitude and latency of the MMN.
Results: A MMN was evoked by both deviant stimuli in all normal hearing participants and in well performing CI users, with similar amplitudes for both groups. However, the amplitude of the MMN was significantly reduced for the poorer CI users compared to the normal hearing group and the good CI users. The latency was longer for both groups of cochlear implant users. A bivariate correlation showed a significant positive correlation between the speech recognition score and the amplitude of the MMN.
Conclusions: The MMN can distinguish between CI users who have good versus poor speech recognition as assessed with conventional tasks.
Significance: Our findings suggest that the MMN can be use to assess speech recognition proficiency in CI users who cannot be tested with regular speech recognition tasks, like infants and other non-verbal populations.

1. Introduction

Individuals with severe-profound bilateral hearing loss who cannot benefit from conventional hearing aids have the option to receive a cochlear implant (CI). This technological device bypasses the outer and middle ear and directly stimulates the fibers of the auditory nerve, restoring some degree of auditory perception. The primary goal of a CI is to permit speech perception, but its success varies greatly among users. With modern multi-electrode CI's, speech performance scores can reach 70–80% for sentence recognition in a quiet environment but for some CI users, speech perception can remain challenging (Osberger et al., 2000; Garnham et al., 2002).

In the field of audiology, behavioral methods such as tests of speech intelligibility are the primary tools used to investigate auditory performance. However, these tests are not always appropriate for the assessment of individuals with prelingual deafness or for those with prolonged auditory deprivation, as they generally present severe deficits in language and speech recognition. In addition, these tests have a restricted use for infants and

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non-verbal adults who are unable to complete behavioral speech testing.

Auditory evoked potentials have been used with considerable success to assess the integrity of the auditory system in paediatric and adult CI users (Kraus et al., 1993; Groenen et al., 1996; Kileny et al., 1997; Roman et al., 2004; Singh et al., 2004; Gordon et al., 2005; Kelly et al., 2005; Dinces et al., 2009). These potentials are neuropsychysiological correlates of auditory perception. In normal hearing subjects, the N1 component peaks generally around 100 ms and has been suggested to arise from Heschl'y gyrus and the Planum temporal (Näätänen, 1990; Woods, 1995). It is followed by a positive P2, culminating at about 200 ms. The amplitude and latency of the N1/P2 complex are indexes of the sensory processing of auditory information. In previous studies, the amplitude and the latency of the N1/P2 complex evoked by pure tones was found to be similar for CI users and normal hearing subjects (Roman et al., 2004). Normal latency has also been found in CI users using speech stimuli (Zhang et al., 2010). However, others found differences between CI users and normal hearing subjects on these measures. For example, Kelly et al. (2005) used pure tones and obtained a smaller N1 amplitude and a larger P2 latency in CI users compared to the normal hearing group. Micco et al. (1995) used speech stimuli (/da/ and /di/) and found that the amplitude of the N1 was reduced in CI users. These electrophysiological methods are proposed as an alternative and complementary measure to behavioral tools.

Among the various types of evoked potentials, the mismatch negativity (MMN) is of particular interest because it provides an objective and non-invasive electrophysiological measure of auditory discrimination. This is non negligible given that auditory discrimination is essential for speech and music perception. The MMN is elicited by a series of rare and deviant stimuli embedded in a sequence of standard stimuli. In adults with normal hearing, the MMN is typically characterized by a negativity that is maximal over the frontocentral electrodes and that occurs approximately 100–250 ms after the onset of the deviant stimulus (for a review see Näätänen, 1990). The MMN can be obtained when no attention is paid to the auditory stimuli, so it is thought to index preattentive discrimination. The presence of this negative waveform indicates that the auditory system responds differentially to stimuli that have different acoustic profiles, suggesting the integrity of the auditory processes underlying this type of discrimination.

A few studies recorded a MMN with pure tones in adults with a CI to investigate the electrophysiological correlates of auditory processing. By means of a 3-stimulus paradigm, Kelly et al. (2005) presented a pure tone of 1000 Hz and two rare pure tones of 1250 Hz and 1500 Hz to 12 adult CI users. Based on their results on speech perception tests, eight participants were identified as good users and four as poor users. Compared to normal hearing participants, the MMN was absent or degraded in the CI users with the poorer speech scores. Moreover, the latency of the MMN and speech score were positively correlated for the condition with the largest difference between the two stimuli (large deviant MMN: 1000 and 1500 Hz). Roman et al. (2004) used tone bursts of 1000, 1500 and 2000 Hz to elicit a MMN in eight normal hearing listeners and seven adults with a CI. Significant correlations were obtained between the latency of the MMN and word discrimination for the condition with the smaller difference between the two stimuli (small deviant MMN: 1000 and 1500 Hz). Recently, three CI users and three normal hearing controls were evaluated using a P300 and a MMN paradigm (the frequent stimulus was 1000 Hz and the rare stimuli were 1500, 2000 and 4000 Hz). For the MMN condition, the CI users had overall longer latencies and a lower amplitude for the 1000–1500-Hz contrast condition (Obuchi et al., 2012). These studies show the importance of using MMN protocols that have more than two stimulus conditions, given that the correlations obtained between the MMN and the speech score were only significant for some of the conditions. These results, albeit from a limited numbers of CI users, suggest that the outcomes of electrophysiological measurements are related to the proficiency of the CI.

Most studies categorize CI users as good versus poor based on their speech recognition performance. Considering the acoustic phonetic information contained in speech syllables (for example /*ba*/), this type of stimuli are more relevant to study speech perception than are pure tones. In fact, when speech stimuli are used to elicit the MMN, it is thought to index preattentive speech discrimination (for a review of speech evoked potentials see Martin et al., 2008). To our knowledge only three studies recorded a MMN with speech stimuli in adult CI users. Kraus et al. (1993) recorded a MMN with the speech stimuli /da/ and /ta/ in ten adults with normal hearing and in nine adults with a CI, all but one considered to be a good user. Performance with the implant was based on subjective reports of satisfaction, everyday communication competence and the ability to understand monosyllabic words. The authors found that the MMN waveforms in the good CI users were similar to those from adults who had normal hearing. The single poor implant user in the study did not produce any MMN. A similar study with seven adult CI users used the speech stimuli /ba/ and /da/ and categorized the CI participants on the basis of their performance with monosyllable, spondee and short vowel identification (Groenen et al., 1996). These results yielded similar conclusions; a MMN was recorded for the good performers ($n = 3$) but not for the poorer performers ($n = 4$). Lastly, Lonka et al. (2004) recorded a MMN with the Finnish speech sounds, /e/, /ø/ and /o/ in five CI users. Speech discrimination and MMN were recorded four times during the first 3 years after cochlear implantation. The authors reported that speech discrimination improved over time. They also found that a prominent MMN was first elicited by the larger phonetic-acoustic difference and then later by the smaller phonetic-acoustic difference. Finally, their results show that the amplitude of the MMN increased over the course of the study. However, likely because of the relatively small number of participants in these studies, no correlations between speech performance and the MMN were performed.

Similar to pure tones, speech syllables can also be chosen based on their acoustic content. This enables to create more than one stimulus pair, thus introducing more than one type of discrimination. The MMN studies that use speech syllables have either a limited number of participants, do not include correlations between speech performance and the MMN, or only used two different speech stimuli. Therefore, the goal of the present study was to investigate the characteristics of the MMN in a two-deviant oddball paradigm using three different speech stimuli (/da/, /ba/ and /ga/). The same vowel is used for each stimulus; however, their co-articulation with a specific consonant differentiates them in terms of acoustical composition. The three stimuli were chosen to induce two discrimination conditions. This enables us to determine which condition is most sensitive to deficits in speech recognition in CI users. We hypothesized that the better the speech performance will be, the closer to the normal group the electrophysiological measures will be. We hypothesize that the CI users with the poorest results on the speech recognition task will also have the greatest deficits on the electrophysiological measure.

2. Methods

2.1. Participants

Twenty experienced adult CI users (mean age = 45 years, SD = 14, min = 20, max = 63) and 11 normally hearing adults (mean