Sentence comprehension in proficient adult cochlear implant users: On the vulnerability of syntax

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This article has been accepted for publication in Language and Cognitive Processes, published by Taylor & Francis.

http://dx.doi.org/10.1080/01690965.2011.653251

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Abstract

Comprehending language via a cochlear implant, a neural prosthesis which stimulates the acoustic nerve electrically, poses a remarkable challenge to the brain. We investigated auditory sentence comprehension in a group of thirteen high proficient adult cochlear implant patients using event-related brain potentials. Four types of sentences were examined: correct sentences with either high (1) or low (2) expectancy of the sentence final word (cloze probability), semantically incorrect sentences (3) and sentences violating the argument structure of the verb (4). Participants judged the acceptability of the sentences. Relative to correct sentences with a high cloze probability all other conditions elicited a N400 effect in both the patient group and a matched control group, although the timing of the effect differed between the two groups. Moreover, whereas the argument structure violation elicited a late positivity in addition to the N400 effect in the control group, no such effect was observable in the cochlear implant group. We take these data to indicate that under adverse input conditions, processes of syntactic repair reflected in the P600 effect, are much more vulnerable than processes of semantic integration reflected in N400 effects.

Acknowledgements:

We thank all CI-patients for their participation. The work was supported by the German Research Foundation (DFG Ha 3153/1-1).

Introduction

Comprehending speech via a cochlear implant device is a prime example of adverse listening conditions. Cochlear implants are hearing prostheses that can restore hearing to profoundly deaf or severely hard-of-hearing people. They bypass the damaged hair cells in the inner ear and stimulate the cell bodies in the spiral ganglion directly. Speech is picked up by a microphone and subsequently a signal processor filters the signal into different frequency channels. Current pulses with amplitudes proportional to the energy of each channel are transmitted to electrodes inserted in the cochlea. Thus a cochlear implant mainly transmits changes in the amplitude of a signal over time, the so-called envelope information, whereas the spectral information is largely reduced. Hence, hearing through a cochlear implant largely differs from normal hearing and the rehabilitation process as well as the ultimate performance shows a great variability across patients (Heydebrand, Hale, Potts, Gotter, & Skinner, 2007).

The knowledge of the neuro-cognitive processes underlying language comprehension in cochlear implant patients is rather scarce. Giraud and colleagues (Giraud et al., 2000, 2001, 2002) investigated the neural basis of speech recognition in cochlear implant patients in several PET studies. They demonstrated that a different network is activated in patients compared to normal hearing controls. When listening to words, sentences, or stories proficient CI patients showed similar behavioral performance but clear differences in brain activation patterns: a relative decrease in activation for semantic areas and a simultaneous increase of phonological areas. The phonological processing of words in normal hearing persons does not allocate many resources, but patients seem to need more processing effort during this analysis stage. In addition, Giraud, Truy, Frackowiak, Grégoire, Pujol & Collet (2000) observed an over-activation of certain brain regions in CI patients compared to normals. When listening to vowels, i. e. non-meaningful speech sounds, semantic areas were over-activated. This effect is interpreted as an implicit top-down modulation supporting the difficult bottom-up perception mechanisms (Giraud et al., 2000). In two studies Giraud and colleagues presented evidence for additional activation of visual areas which they interpreted as reflecting increased lip reading processes compensating for the degraded auditory input (Giraud et al, 2001; 2002).

Another research line that has been established during the last years examines simulations of cochlea implants. In a seminal paper Shannon et al. (1995) introduced so-called noise-vocoded speech as a simulation of electric stimulation via an implant. Speech is divided into a number of defined frequency bands (e.g., six) and the amplitude envelope is extracted from each band. These envelopes are then applied to band-limited white noise in the same frequency ranges (cf. Davis et al., 2005). This procedure removes spectral details and keeps only temporal cues and thus resembles the processing of current cochlear implant devices. Studies using noise- or sine-wave vocoded speech showed that high levels of speech recognition can be achieved with as few as four frequency bands of envelope information as normal hearing participants presented with noise-vocoded speech were able to reach a high performance level after some training.

Several follow-up studies demonstrated that normal hearing persons are capable of adjusting to this degraded input after only a short training period. Besides changes in the prelexical representations, it could be demonstrated that a top-down, lexically driven mechanism is involved in learning noise-vocoded speech (Davis et al., 2005; Loebach & Pisoni, 2008; Loebach, Pisoni & Svirsky, 2010). An obvious advantage of testing normal hearing participants compared to examining CI-patients is that relevant variables, such as age, duration of deafness, educational level etc., can be easily controlled for. However, studies using CI simulations suggest clear differences compared to clinical observations in CI-patients. The learning process observed with noise-vocoded speech is much quicker than that documented with CI patients. Consequently, the negotiability on cochlear implant processing is limited and simulation experiments cannot replace studies in CI patients.

In the present study we used event-related brain potentials (ERPs) in order to get insight into sentence comprehension mechanisms in a group of postlingually deaf CI patients. ERPs are an established method for analyzing language comprehension in normal hearing adults, but have been used also to study different patient groups as well as developmental aspects (for reviews see Duncan et al., 2009; Friederici, 2006). So far, this method has been applied on CI patients only for analyzing early auditory processing steps but not for higher cognitive processes. The two most prominent ERP components observable in relation to sentence processing are the N400 and the P600 component. While there is an on-going debate about the precise functional interpretation of these components (Bornkessel-Schlesewsky & Schlesewsky, 2008; Friederici & Wartenburger, 2010; Kutas, Van Petten & Kluender, 2006; Steinhauer & Conolly, 2008), it is safe to say that the N400 component varies as a function of the semantic expectancy within a sentence and presumably reflects semantic integration processes. The P600 component is elicited in sentences that carry a syntactic violation, but also for syntactically more complex relative to less complex sentence constructions (Kaan, Harris, Gibson, & Holcomb, 2000; Friederici, Hahne & Saddy, 2002). It is interpreted as a reflection of syntactic repair processes or more generally as a reflection of „unexpected events at the sentential level" (Friederici & Wartenburger, 2010).

In the present study we made use of the violation paradigm which was introduced in the seminal study of Kutas & Hillyard (1980). We presented four different types of sentences, two correct and two incorrect ones. The correct sentences ended either with a highly expected word (high cloze probability) or with a word that was less predictable (low cloze probability). Incorrect sentences ended either with a semantically incongruous word or with a word violating the argument structure. It is a well established fact that the amplitude of the N400 component is inversely correlated with the cloze probability. Semantic violations can be seen as maximally low cloze probability sentences and thus elicit greater N400 components than correct low cloze sentences (Kutas & Hillyard, 1984). Argument structure violations arise whenever the number of arguments in a sentence does not correspond with the number of arguments specified in the lexical entry of the verb. For example, a sentence like "Jack sneezes the doctor" is incorrect as the verb sneeze only provides an "actor" but no other possible thematic roles. These types of violations have been shown to be correlated with a N400 component followed by a P600 component (Friederici & Frisch, 2000; Frisch, Friederici & Hahne, 2004; Osterhout et al., 1994; Rösler, Friederici, Pütz & Hahne, 1993). The N400 in this case is thought to reflect a semantic problem which arises when the argument noun phrase is not provided with a thematic role by the verb. The P600 on the other hand is thought to reflect the processing of a syntactic problem, namely that the transitive structure is not licensed by the intransitive verb.

As we tested only high proficient CI patients, we expected that they should be able to understand the majority of the words correctly and thus have access to the whole information of the words stored in the mental lexicon. This means that they should be able to comprehend the sentences and recognize the violations. The aim of the present study was to examine whether the cognitive processes underlying sentence comprehension in these patients is comparable to normal hearing adults. In an earlier sentence processing study we observed that the degraded input did not substantially affect semantic integration processes. Rather we observed semantic compensation processes at the expense of syntactic processing (Hahne, Wolf, Müller & Friederici, 2009). If this is indeed a general mechanism, we expect again N400 effects reflecting semantic processing but no P600 effect reflecting syntactic repair processes.

Methods

Participants.

Thirteen postlingually deaf CI-users (mean age 51 years, range 34 – 63; six female) and thirteen control subjects participated in the experiment. The controls were matched on age

(+/- 3 years), sex and educational level. All participants were native speakers of German. Their written consent was obtained, in accordance with the declaration of Helsinki. In recruiting the patients we preselected them on the basis of their comprehension abilities: all patients had good comprehension with their cochlear implant in free-field situations as for example demonstrated by the ability to communicate via telephone and >70% correct understanding of monosyllables. All patients were fitted with a Combi 40+ cochlear implant (MED-EL) using the CIS strategy. Nine patients were implanted at the left side and four at the right side. Three patients were usually wearing a conventional hearing aid on the contra lateral side. Age at implantation varied between 33 and 62 years (mean 50 years), CI usage varied between 8 and 66 months (mean 28 months). Residual hearing neither on the implanted side nor on the contralateral side allowed word comprehension in any of the patients.

Materials.

The stimulus material consisted of four experimental conditions with 42 sentences each (see Rösler, Friederici, Pütz & Hahne, 1993). All sentences were passive constructions consisting of a NP, the auxiliary “wurde” and a past participle. Correct sentences were either of high (a) or low (b) cloze probability (cf. Bloom & Fischler, 1980; Taylor, 1953). In a written pretest 88 students were requested to fill in the terminal word of the sentences. The cloze probability of a word is defined as the proportion of participants using that word in a particular sentence. Incorrect sentences were either selectional restriction violations (c) or violations of verb argument structure (d). Whereas conditions a-c consisted of transitive verbs, condition (d) contained an intransitive verb. Thus, in condition (d) the subject position is filled with an argument NP, whereas the verb does not provide a thematic role for this position. In all sentences the correctness versus incorrectness of the sentence was evident on the participle. The sentences were spoken in a pseudo-randomized order by a trained female native speaker of German and recorded onto digital audio tape. They were then digitized at a sampling rate of 44 kHz and the onset of the verb was identified and triggered by a careful auditory and visual inspection of speech signal to ensure a precise time locking of the ERP in each individual sentence.

(a)	Correct, high cloze probability	Der Tisch wurde gedeckt. (The table was being laid.)
(b)	Correct, low cloze probability	Der Bruder wurde geimpft. (The brother was being inoculated.)
(c)	Incorrect, selectional restriction violation	*Der Ozean wurde gestrickt. (The ocean was being knit.)
(d)	Incorrect, argument structure violation	*Der Hund wurde gebellt. (The dog was being barked.)

Procedure.

Participants were seated in a comfortable chair in a sound-attenuated booth, 100 cm in front of a computer screen. The auditory stimuli were presented via loudspeakers. The sound intensity was adjusted individually to a comfortable level as indicated by the patient. Control participants were tested at 65dB SPL. In case patients usually had a conventional hearing aid on the contra-lateral side, this was switched-off during the experiment. Each trial started with a fixation signal (*) appearing on the screen 500 ms before sentence onset. It remained visible until it was replaced by a response cue appearing 1500 ms after the end of the sentence. The cue was presented for 2 sec. Participants were required to judge the sentences for correctness by pressing one of two buttons during the presentation of the response signal. The inter-trial interval was set at 1500 ms. Participants received written instructions including example sentences. They were asked to avoid movements during the presentation of the fixation signal. The experimental session was divided into four blocks containing 42 sentences each, with short pauses in between. Prior to the experimental blocks sixteen example sentences were presented. Sentences were presented in two pseudo-randomized orders equally distributed across participants. They were obtained using the following constraints: First, sentences from the same condition were not presented in more than three consecutive trials. Second, no more than four correct or incorrect sentences were presented in succession.

Electrophysiological recordings.

The EEG was recorded with 17 monopolar Ag/AgCL electrodes mounted in an elastic cap from Fz, Cz, Pz, F3/4, F7/8, CP5/6, FT7/8, P3/4, P7/8, O1/2. For CI users, the mastoid electrode contralateral to the implanted side was used as reference electrode. For control participants the recordings were referenced to the left mastoid. The activity over the right mastoid was actively recorded and off-line, these recordings were rereferenced to the right mastoid recording in case the counterpart CI patient had a right reference electrode. Horizontal and vertical electrooculograms were bipolarly recorded. Electrode impedance was kept below 5 kOhm. The biosignals were amplified within a bandpass from DC to 40 Hz and digitized with 250 Hz.

Data analysis.

Error analyzes were computed separately for each condition. ERP analyzes were restricted to trials in which participants had responded correctly. As the lateral electrodes were subject to implant-related artifacts, we restricted our analyzes on the three midline electrodes Fz, Cz and Pz. Although recently there have been some suggestions on minimizing these artifacts (e.g., Gilley et al., 2006; Rahne, von Specht & Mühler, 2008; Sandmann et al., 2009), these techniques are not suitable for the present data as they imply a large number of recording electrodes (but see Gilley et al. (2006) for testing the optimized differential reference method in a single subject). CI-artifacts in midline positions are rather small (cf. Figure 1A). However, our main focus is on the interpretation of difference waves where the influence of CI artifacts is negligible (cf. Figure 1B). Trials with typical EOG movement artifacts were corrected using an EOG correction tool (“xeog”, part of EEP software by M. Grigutsch), all other trials contaminated by ocular or movement artifacts were rejected. Rejections were equally distributed across the two groups (CI patients, controls) and the four conditions (main effects and interaction: all $Fs < 1$; mean number of rejected trials (CI patients/ controls): correct-high cloze: 1.3/1.6, correct-low cloze: 1.7/1.8, semantic: 1.5/1.5, argument 1.2/1.5). ERPs were computed for each participant in each experimental condition for 1500 ms time-locked to the onset of the critical past participle relative to a 200 ms prestimulus baseline. Based on previous studies with normal hearing participants we expected an N400 effect relative to the correct, high cloze condition for all three conditions for the control group as well as for the CI group. In addition, a P600 effect was expected for the argument structure violation at least for the control group. In order to evaluate N400 effects, including latency differences across groups, statistical analyses of mean voltage were performed in two time windows: 300-700 ms (TW1), and 700-900 ms (TW2). To analyze P600 effects we used the time window 900-1200 ms (TW3). All analyzes were quantified using the multivariate approach to repeated measurements with the between subject variable “group” (CI patients versus controls) and the within subject variables “time window”, “condition” and “electrode”. In case of significant interactions including the variables group and condition, separate analyses exploring these interactions were conducted. The correct condition, high cloze probability (a) served as comparison for the three other experimental conditions. The Greenhouse-Geisser correction (Greenhouse & Geisser, 1959) was applied when evaluating effects with more than two degrees of freedom in the numerator. Below, we report uncorrected degrees of freedom and corrected probabilities.

Results

Behavioral data.

The analysis of error rates in the delayed response task revealed that CI patients made significantly more errors than control subjects (correct-high cloze: 0.9 (controls), 8.1 (CI); correct-low cloze: 2.0 (controls), 11.7 (CI); selectional restriction violation: 0.5 (controls), 5.9 (CI); argument structure violation: 0.7 (controls), 5.7 (CI); main effect group: $F(1,24) = 31.3$, $p<.001$). In addition, there was a main effect of condition ($F(3,72) = 7.9$, $p<.001$) and a reliable interaction of group and condition ($F(3,72) = 3.1$, $p= .05$). Bonferroni-corrected pairwise comparisons revealed that in the patient group significantly more errors were made in the correct low cloze condition than in the high cloze condition. The comparisons of the low cloze condition with the two incorrect conditions were marginally significant whereas there were no reliable effects in the control group. As the judgment was given 1500 ms after the offset of the sentences, mean reaction times cannot be considered as an online measure for sentence comprehension and they were not analyzed.

ERP data.

The ERP waveforms for both groups for all conditions are displayed in Figure 1. In addition, Figure 1 includes the difference waves between the three experimental conditions (semantic, argument structure, correct-low cloze) and the correct-high cloze condition for each group. The data show a large positivity across conditions for the patient group which is not visible for the control group. An evaluation of the difference waveforms suggests that there are large similarities across groups with the exception of a late positivity which is present for the controls but not for the patients. The statistical analyzes confirmed these descriptions.

Correct condition. As the correct-high cloze condition showed large differences across groups, we analyzed the mean amplitude in this condition for the two N400 windows as well as for the P600 time window. An overall analysis revealed besides highly significant main effects of time window ($F(2,48) = 17.2$, $p <.0001$) and group ($F(2,48) = 11.2$, $p <.0001$), a highly reliable interaction between group and time window ($F(1,24) = 8.7$, $p <.001$). Subsequent analyses were performed for each time window separately. Whereas there were no reliable group effects in TW 1, there were significant main effects of group in TW2 ($F(1,24) = 8.71$, $p<.01$) as well as in TW3 ($F(1,24) = 22.45$, $p<.0001$).

Analyses of specific ERP effects relative to the correct-high cloze condition.

Correct-low cloze. Besides a main effect of condition, the overall analysis including the two N400 time windows revealed marginally significant interaction between group x condition x time window as well as a marginally significant four-way interaction (see Table 1). These interactions licensed analyses for each time window separately. TW1 revealed a main effect of condition ($F(1,24) = 24.08$, $p<.0001$). There was no significant main effect of condition in TW2 and TW3 ($F<1$), however, a reliable main effect of group (TW2: $F(1,24) = 4.74$, $p<.04$; TW3: $F(1,24) = 18.04$, $p<.0001$) and a marginally significant interaction of group and condition in TW2 ($F(1,24)= 3.90$, $p<.06$) was observed. Separate analyzes for the two groups showed that there was a significant interaction of condition and electrode in patients ($F(1,12) = 14.09$, $p <.0001$) but not in controls (condition: $F < 1$; interaction: $F(1,12) = 1.70$, $p<.21$). The interaction of condition and electrode in the patient group was due to the fact that the condition effect was restricted to CZ and PZ. Thus we observed a statistically reliable N400 effect for the low cloze as compared to the high cloze condition in both groups. The effect had a longer extension in the patient group.

Semantic violation. The global analysis revealed a reliable interaction of condition, group and time window besides main effects of group and condition (see Table 1). To explore this interaction we performed separate analyses for each time window. In TW1 there was a highly reliable main effect of condition ($F(1,24) = 35.00$, $p<.0001$). An interaction of condition and electrode ($F(2,48) = 19.02$, $p<.0001$) revealed the fact that the effect was more pronounced on CZ and PZ than on FZ. TW2 revealed a significant condition effect ($F(1,24) = 7.28$, $p<.012$). Furthermore there was a significant interaction of group and condition ($F(1,24) = 4.61$, $p<.04$). Therefore we analyzed each group separately. The main effects of condition ($F(1,12) = 15.76$, $p<.01$) as well as the interaction of condition and electrode ($F(2,24) = 6.11$, $p<.05$; FZ: $p = <.10$, CZ: $p <.01$, PZ: $p<.0001$) were significant in patients whereas there were no reliable effects in the control group.

Taken together, the data showed a clear N400 effect for both groups which, however, lasted longer in the patient group.

<u>Argument structure violation.</u> The overall analysis including three time windows revealed at least marginal significance for all effects tested except a main effect of condition and the interaction of group with condition and electrode (Table 1). The reliable interactions including the variable time window motivated analyses for each of the three time windows separately. The main effect condition was highly reliable in TW1 ($F(1,24) = 33.02$, $p <.0001$) but not in TW2 ($F<1$). A significant interaction of condition and group in TW2 ($F(1,24) = 4.43$, $p<.05$) led to separate analyzes for each group. A significant main effect of condition was observed for the patient group ($F(1,12) = 5.04$, $p <.05$) but not for the control group ($F<1$). The effect in the patient group was restricted to CZ and PZ (interaction condition x electrode: $F(2,24) = 15.42$, $p<.001$). Analysis of TW3 showed a significant interaction of group and condition ($F(1,24) = 5.15$, $p<.05$). Separate analyzes for the two levels of the group variable showed a significant main effect of condition for the control group ($F(1,12) = 8.67$, $p<.01$) but not for the patient group ($F<1$).

In sum, the data for the argument structure violation revealed a N400-P600 complex in the control group but only a N400 effect in the patient group.

As the range of CI usage in our group varied from 8 to 66 months, this broad range may have influenced the reported results. Therefore we tested whether the significant effects for the patient group (difference relative to the high cloze condition) correlated with the length of CI usage. However, all correlations were far from reaching significance demonstrating that the patients' comprehension abilities had already reached a plateau level.

Discussion.

The present study investigated auditory sentence comprehension under degraded input conditions. Adult high proficient cochlear implant patients listened to and judged short passive voice sentences. Their performance in the acceptability judgment task confirmed their high language comprehension ability in an open-field situation. Although the error rate in the patient group was larger than in the control group it was rather low in absolute terms (mean 7.5 %).

N400-effect.

ERPs demonstrated that modulations of the N400 effect (i.e., effects relative to the correct high cloze condition) could be observed in each experimental condition similar to the control group. Variations, however, were seen in latency measures with the cochlear implant group having longer latencies. Thus, degraded input conditions resulted in delayed semantic integration processes.

In contrast to the overall qualitative similarities with regard to the N400-effects, there were two fundamental differences across groups. First of all, the overall appearance of the waveforms differed markedly across groups with the CI group eliciting much more positive going ERPs than the controls. This was true even for the correct sentences with a high cloze probability. Cochlear implant patients produced a much larger positivity in response to these sentences than did control subjects. This huge positivity peaked about 125 ms later than the small positive wave elicited by controls. In the literature the late positivity has been reported in correlation with the processing of incorrect relative to correct sentences, but also for syntactically complex relative to easier sentences (Friederici, Hahne & Saddy, 2002; Kaan et al., 2000). The latter positivity was interpreted to reflect syntactic integration difficulty present even for correct sentences.

Interestingly, a similar data pattern as for the present CI group was seen in groups of children with six, seven and eight years of age to comparable short passive voice sentences (Hahne, Eckstein & Friederici, 2004). Furthermore, we observed large positivities for similar correct sentences in low proficient foreign language learners (Hahne & Friederici, 2001). Given this similarity to first and second language learners one might speculate that the observed positivity reflects general higher processing demands in these groups than in healthy adult native speakers. It is important to note, however, that the underlying reason for increased processing demands is located at different levels in the processing hierarchy: at the central level in language learners with a not (yet) fully developed language system, and at the peripheral level in cochlear implant patients with a reduced input. Support for such an explanation also comes from noise-vocoded speech fMRI studies which observed increasing (mid to anterior) STG activity with decreasing intelligibility (Friederici, Kotz, Scott, & Obleser, 2010; Scott & Johnsrude, 2003; Obleser et al., 2007).

P600 effect.

The second fundamental difference across groups refers to the P600 effect (i. e., a positivity relative to the correct condition) in the argument structure violation condition which was elicited only in the control group but not firmed for the patient group. In a similar study with high proficient CI patients we examined a syntactic phrase structure violation condition (Hahne et al., 2009). A P600 effect was only elicited in a few extremely good performers whereas suboptimal performers produced an N400 effect instead. While in the former study the relevant information was a short unstressed preposition, the relevant syntactic information in the present study is coded in the lexical entry of the verb and thus possibly easier accessible than an unstressed function word, i.e. a preposition. Despite the accessibility of the syntactic information in the argument structure violation there is no indication of applying it to repair incorrect argument licensing. Therefore the data suggest that in case of adverse input conditions processes of syntactic repair reflected in the P600 effect, are much more vulnerable than semantic integration processes reflected in N400 effects. This corresponds to a basic strategy hearing-impaired individuals refer to in everyday life: focusing on semantic keywords and interpreting them even if some details of the sentence have not been understood. Interestingly, a similar data pattern has been reported for agrammatic aphasic patients suffering from a syntactic deficit caused by cortical brain lesion. In a semantic task, Hagoort, Wassenaar & Brown (2003) observed a P600 effect for word order violations in control subjects and non-agrammatic aphasics, whereas agrammatic aphasics however, did not show a P600 effect. Agrammatics rather showed a N400 effect which was interpreted as a semantic compensation of the syntactic deficit. With regard to this analogy it is important to notice that the deficit in aphasics is localized on a central level whereas it is on a peripheral level in cochlear implant patients. The combined data suggest that a focus on semantic information seems to be a successful strategy under different kinds of processing deficits.

Electrical artifacts.

As the auditory evoked potentials in cochlear implant users are known to be affected by electrical artifacts which implant devices create during stimulation, it is worth to discuss whether these undermine the ERP effects presented here. First of all, it is important to note that we focus on the interpretation of ERP differences waves, i.e. on ERPs to unexpected or incorrect sentences relative to ERPs for highly expected, correct sentences. As the terminal word of the sentences was very comparable across conditions regarding acoustic properties (length, prosody, all participles starting with the participle marker “ge-“) the difference waves are per se not significantly influenced by electrical artifacts. Furthermore, we only refer to very late ERP effects starting at 300 ms post target onset where the auditory stimulation is almost completed. In fact a detailed inspection of Figure 1 comparing absolute ERPs (A) and difference waves (B) reveals that approximately the first 300 ms of the absolute ERPs but not of the difference waves are characterized by rather sharp peaks in the CI group which are caused by the electric stimulation. This effect was much larger at lateral electrode sites and therefore we analyzed only the midline positions in the present paper. The difference waves, however, seem to be rather unaffected by the electric stimulation and are overall similar to the control group and can therefore be readily interpreted.

Conclusion.

The present study showed that degraded input as exemplified in cochlear implant users slows down language comprehension processes and may even cancel out specific subprocesses, with syntactic processes being more susceptible than semantic processes.

Overall, the present study demonstrated that late ERPs are a valuable tool in examining the processes underlying language comprehension in cochlear implant patients.

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Figure legends:

Figure 1.

A: Grand average ERPs time locked to the onset of the participle (N=13) for the four experimental condition for the matched control group and the cochlear implant group. B: Difference waves: the correct high cloze probability condition is subtracted from the other conditions, respectively. Negativity is plotted upwards.

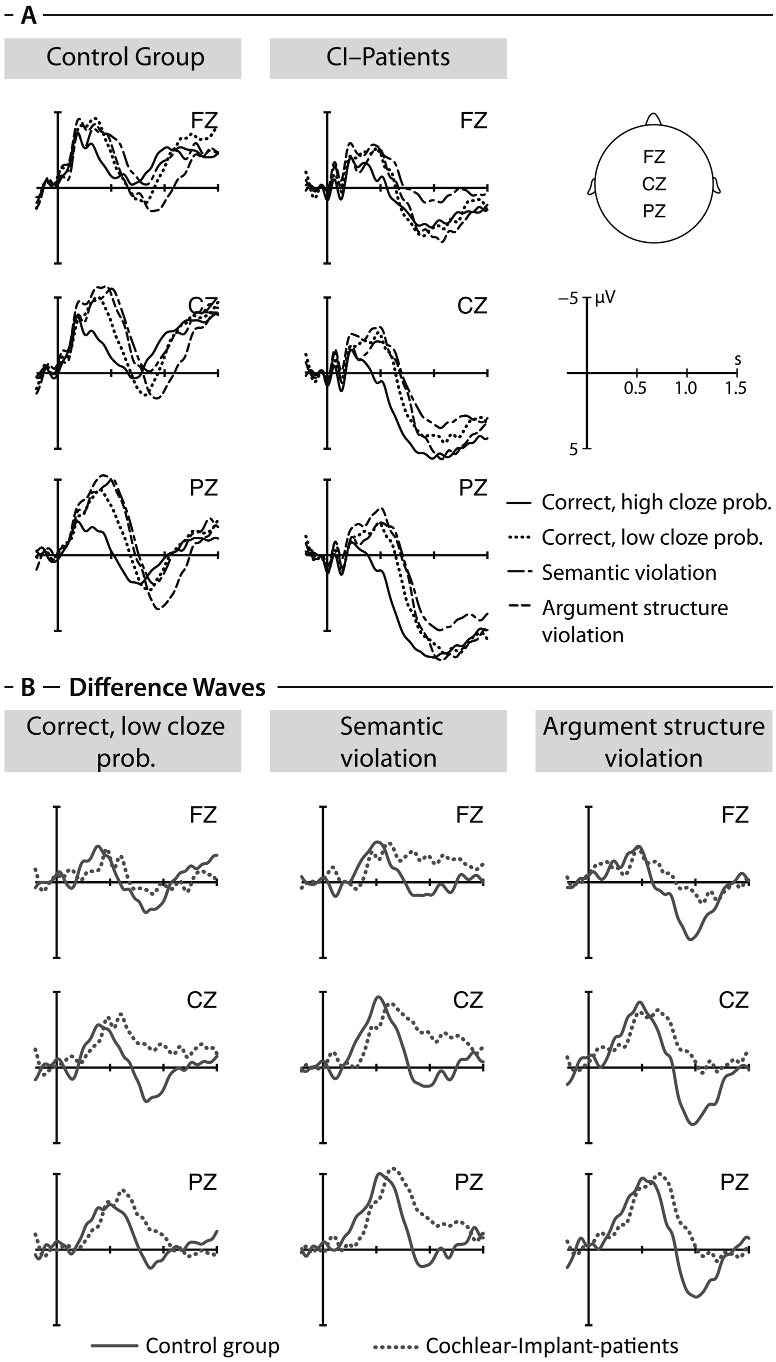
A
Control Group
CI–Patients
FZ
CZ
PZ
−5 μV
s
0.5
1.0
1.5
5
Correct, high cloze prob.
Correct, low cloze prob.
Semantic violation
Argument structure violation
B
Difference Waves
Correct, low cloze prob.
Semantic violation
Argument structure violation
Control group
Cochlear-Implant-patients

Table 1. Global analyses of ERP effects for the three conditions (relative to the correct, high cloze probability condition).

	Correct, low cloze probability			Selectional restriction violation			Argument structure violation		
	df	F	p	df	F	p	df	F	p
group	1,24	3.14	.09	1,24	4.38	.047	1,24	6.97	.01
cond	1,24	5.58	.03	1,24	24.05	.0001	1,24	1.55	.23
group x cond	1,24	2.24	.15	1,24	1.31	.26	1,24	3.52	.07
group x cond x tw	1,24	3.54	.07	1,24	6.86	.02	2,48	4.75	.02
group x cond x elec	2,48	1.33	.27	2,48	< 1		2,48	< 1	
group x cond x tw x elec	2,48	3.04	.08	2,48	2.76	.09	4,96	2.79	.05

Note. Cond = condition; tw = time window; elec = electrode. The analysis of the correct, low cloze and the selectional restriction violation included the two N400 windows (300-700 ms, 700-900 ms), the analysis of the argument structure violation included additionally the P600 time window (900-1200 ms).