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Reproduction of auditory and visual standards in monochannel cochlear implant users

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Abstract. The temporal reproduction of standard durations ranging from 1 to 9 seconds was investigated in monochannel cochlear implant (CI) users and in normally hearing subjects for the auditory and visual modality. The results showed that the pattern of performance in patients depended on their level of auditory comprehension. Results for CI users, who displayed relatively good auditory comprehension, did not differ from that of normally hearing subjects for both modalities. Patients with poor auditory comprehension significantly overestimated shorter auditory standards (1, 1.5 and 2.5 s), compared to both patients with good comprehension and controls. For the visual modality the between-group comparisons were not significant. These deficits in the reproduction of auditory standards were explained in accordance with both the attentional-gate model and the role of working memory in prospective time judgment. The impairments described above can influence the functioning of the temporal integration mechanism that is crucial for auditory speech comprehension on the level of words and phrases. We postulate that the deficits in time reproduction of short standards may be one of the possible reasons for poor speech understanding in monochannel CI users.

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INTRODUCTION

Temporal reproduction is one of the experimental methods applied in studies concerning prospective time judgment. With this method subjects know before the presentation of the standard that its duration is to be estimated. This method does not require the use of conventional time units and is strongly influenced by attentional and working memory resources (Block et al. 1999, Fortin 1999, Zakay and Block 2004). According to Pöppel's model of time perception, the reproduction of intervals can also reflect the operation of the temporal integration (TI) mechanism that binds together individual events into one perceptual unit that is limited in time up to a few seconds (Pöppel 1994, 1997). In experimental studies using this method – independently of the stimulus modality – it can be observed that standards within the range of the TI mechanism (up to approximately 2-3 s) are reproduced relatively accurately or slightly over-reproduced, whereas longer standards (above 2-3 s) are under-reproduced because they are beyond the limit of the TI mechanism (Kagerer et al. 2002, Pöppel 2004, Szelag et al. 2002).

It may be also assumed that TI is one of the mechanisms creating the neuronal basis for auditory speech comprehension (Szelag and Pöppel 2000, Szelag et al.1997, 2004, Turner and Pöppel 1983, 1988). Experimental evidence shows that, independently of the language (e.g., Polish, English, German, or Chinese), fluent speech has a specific temporal segmentation: phrases lasting 2-3 seconds are separated with short pauses (Pöppel 1994, Vollrath et al. 1992). It is also known that some patients with aphasia, resulting from brain damage, display deficits in speech comprehension not only on the level of single units of language, phonemes, but also on the level of words and sentences (e.g., Lezak 1995). It may be assumed that the latter deficits are associated with disordered information processing in the time domain of a few seconds. Accordingly, our previous studies on the integration of metronome beats showed specific disorders in this process for Broca's aphasics who also demonstrated "telegraphic" output of speech, thus, a reduced duration of uttered phrases (Szelag et al. 1997). Another example of deficits on the level of sentences comes from patients who underwent the cochlear implant (CI) operation. It is well known that this operation allows postlingually deafened people to restore hearing and auditory comprehension (Hochmair-Desoyer and Hochmair 1996, Rauschecker and Shannon 2002, Wilson 1993). However, the level of restored speech comprehension is strongly differentiated across this group of patients. In particular, patients equipped with a monochannel implant display serious comprehension deficits, despite long postoperative auditory training and intensive speech therapy.

The aim of this study is to investigate temporal processing in the range of a few seconds in monochannel CI recipients. As mentioned above, this time range corresponds to the duration of single words and phrases. Thus, it can reflect a patient's functioning on the level of pre-semantic information processing in the time frame of these language units. This functioning may be related to auditory comprehension on the level of words and phrases. The further aim of our experiments is to compare patients' performance in the impaired auditory modality and the intact visual modality.

METHODS

Subjects

Twelve post-lingually deafened monochannel cochlear implant recipients (MED-EL Comfort, 5 women, 7 men) took part in the experiment. All subjects were right-handed as verified by the Edinburgh Handedness Inventory (Oldfield 1971) and were within normal limits of cognitive abilities (Raven Standard Progressive Matrices). They did not use any medication that affected the central nervous system and, apart from deafness, they showed to be in the normal range after neurological examination. All subjects had received intensive auditory training and speech therapy. Their level of auditory comprehension was assessed with a test battery consisting of six subtests: phonemic hearing, vowels, consonants, monosyllabic words, numbers and sentences. CI patients showed a rather low and very differentiated level of speech comprehension: the maximum score was 75% (mean from 6 subtests), the minimum was 11% and the group mean was 45.5%. Further details concerning each patient are given in Table I.

The control group consisted of twelve subjects with normal hearing, matched for age, sex and the level of education. Written consent was obtained from each participant.

Material

Two kinds of stimuli were used, which indicated the duration of both presented standards and reproductions.

Table I

Clinical description of cochlear implant patients

Patient	Sex, age (yrs)	Duration of deafness	Etiology	Period of hearing with implant (yrs)
1	F (26)	2 years	Autoimmunologic	8
2	F (59)	14 years	Progressive loss, otosclerosis	6
3	F (54)	8 years	Progressive loss, otitis media	6
4	F (49)	1 year	Progressive loss, otitis media	8
5	F (45)	2 years	Trauma	7
6	M (60)	14 years	Influenza	8
7	M (44)	1 year	Meningitis	8
8	M (66)	12 years	Meningitis	4
9	M (61)	8 months	Meningitis	8
10	M (20)	3 years	Meningitis	4
11	M (66)	11 months	Influenza	8
12	M (34)	7 years	Meningitis/trauma	8

The auditory stimulus was a pure tone of 300 Hz frequency, presented in the free field at a comfortable listening level. The visual stimulus was a green rectangle (the height was 4.3° and the width was 7.4°), presented on a black computer screen 0.9 m apart from the subject. The luminance level of the rectangle was 10.1 cd/m^2. The luminance level in the chamber, as measured on the wall behind the subject, was 0.84 cd/m^2. The set of exposure times for each stimulus consisted of 11 standard durations: 1, 1.5, 2, 2.5, 3, 3.5, 4, 5, 6, 7 and 9 s.

Procedure

The experiment was conducted in a soundproof chamber. Each subject was tested individually and was seated in front of a computer screen. The task was to reproduce the duration of the exposed auditory or visual standards. After the presentation of a standard duration the stimulus reappeared after a two-second pause (an empty interval). The subjects responded by pressing the button placed on a metal response box (12.5 × 25.5 cm), located on a table in front of the subject. The subjects were asked to press the button (which ended the stimulus presentation) when they judged that the duration of the standard was reached. The reproduced interval lengths were recorded by a computer program with the accuracy of ± 0.5 ms. The inter-trial interval was 3 s.

The experiment proper was preceded by a preliminary experimental session in which 20 practice trials were presented in a random order. To be included into the experiment proper, each subject had to reproduce nearly correctly (the reproduced duration not exceeding ± 20% of the standard presented) a minimum of 5 durations. During this preliminary session feedback about response correctness was given.

The auditory and visual stimuli were presented in two different experimental sessions lasting approximately 45 min each. A single session consisted of 77 trials, each standard was given 7 times in random order. All participants were requested not to use any chronometric counting.

RESULTS

The accuracy of reproduction (assessed by the difference between the presented standard duration and the subject's response) was analyzed for each standard duration and modality. Accordingly, over-reproduction was observed when the subject's response was longer than the presented standard duration and under-reproduction when the subject's answer was shorter than the presented standard duration. The group differences were analyzed using the Mann-Whitney U test, because of the small number of participants and our inability to assume normal distribution of the variables of interests, as well as unequal sizes of compared sub-groups. We considered the difference to be significant when $P<0.05$.

Table II

Speech comprehension scores achieved by cochlear implant users in each of six subtests

Patient	Phonemic hearing	Vowels	Consonants	Numbers	Monosyllabic words	Sentences	Mean
1	97	75	48	100	42	87	75
2	69	50	31	85	25	41	50
3	78	33	46	95	22	36	52
4	70	46	35	65	3	16	39
5	66	42	29	95	8	25	44
6	75	42	29	92.5	8	23	45
7	83	62.5	58	100	38	71	69
8	80	54	44	100	40	89	68
9	75	58	29	72.5	5	26	44
10	59	25	12.5	60	0	1	26
11	42	21	8	62.5	0	5	23
12	53	8	6	0	0	0	11

There was no difference in performance between patients and controls for both auditory and visual tasks. In both groups subjects relatively accurately reproduced standards up to ca. 3-4 s and underestimated standards of longer durations. As the results for CI users on the applied language tests were highly variable (Table II), Spearman correlations were performed to determine whether there was any relationship between the level of auditory comprehension and the accuracy of reproduction for particular standards. For the auditory task there was a significant positive correlation between the accuracy of reproduction for standards of 2.5 s duration, and the score achieved for each of six subtests, and also between the accuracy for standards of 3 s and the following subtests: numbers, monosyllabic words and sentences. Occasional correlations for 1.5, 2, 3.5 and 4 s standards and comprehension level were also observed (see Table III for exact r and P values). There was no significant correlation between auditory comprehension and the accuracy of reproduction for any of the presented standards in the visual modality.

To explore further the relationship between the accuracy of reproduction and auditory comprehension, we divided the group of CI users into two sub-groups on the

Table III

Correlation between the speech comprehension scores in each of six subtests and the accuracy of reproduction for particular standards

	Standard duration (s)							
	1	1.5	2	2.5	3	3.5	4	5-9
Phonemic hearing	ns	-0.59*	-0.59*	-0.65*	ns	ns	ns	ns
Vowels	ns	ns	ns	-0.79**	ns	-0.63*	-0.65*	ns
Consonants	ns	ns	ns	-0.64*	ns	ns	ns	ns
Numbers	ns	ns	ns	-0.62*	-0.65*	ns	ns	ns
Monosyllabic words	ns	ns	ns	-0.72**	-0.69*	ns	ns	ns
Sentences	ns	ns	ns	-0.71*	-0.66*	ns	-0.58*	ns
Mean	ns	ns	ns	-0.66*	ns	ns	ns	ns

*P<0.05, **P<0.01

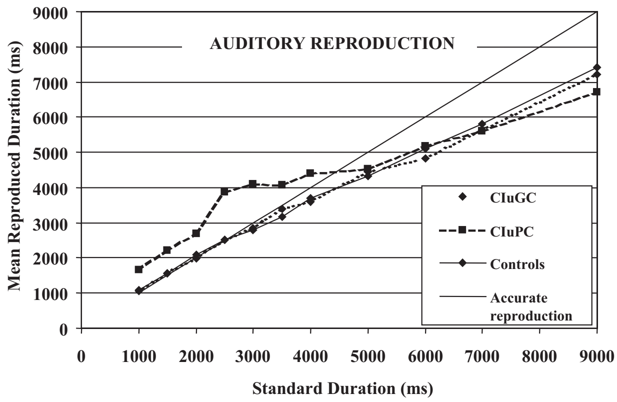

Fig. 1. Mean reproduced durations for different auditory standards in cochlear implant users with poor auditory comprehension (CIuPC), cochlear implant users with relatively good auditory comprehension (CIuGC) and normally hearing subjects.

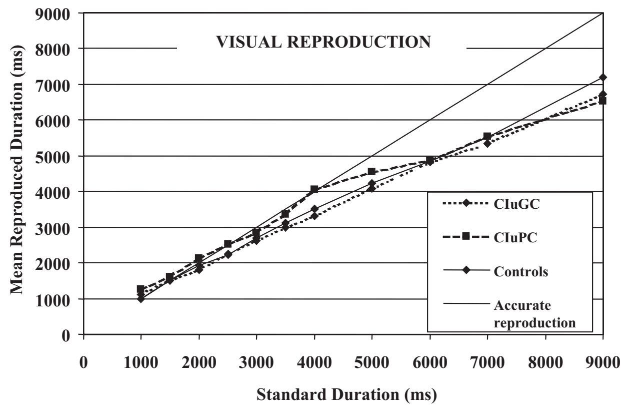

Fig. 2. Mean reproduced durations for different visual standards in cochlear implant users with poor auditory comprehension (CIuPC), cochlear implant users with relatively good auditory comprehension (CIuGC) and normally hearing subjects.

basis of the level of their comprehension abilities. As the maximum score for comprehension was 75% of correctness (Table II, the mean value), scores below 50% of this value (up to 37.5% correct) were considered as representing poor comprehension, whereas scores above 37.6% represented relatively good comprehension. Accordingly, the sub-group of CI users with poor speech comprehension (CIuPC) comprised 3 subjects and the sub-group of CI users with relatively good comprehension (CIuGC) comprised 9 persons. We compared the performance between these two sub-groups and control subjects for both auditory and visual tasks.

For the auditory task there was no difference between CIuGC and controls (Fig.1). In both these groups subjects relatively accurately reproduced standards up to approx. 2.5-3 s and underestimated standards of longer durations.

In contrast, CIuPC reproduced auditory standards of 1, 1.5 and 2.5 s duration as significantly longer ($Z = 2.31, P<0.02$; $Z=2.02, P<0.05$ and $Z=2.02, P<0.05$, respectively) in comparison with controls, as well as standards of 1, 2 and 2.5 s ($Z=-2.31, P<0.02$) in comparison with CIuGC (Fig. 1).

There were no differences between the two sub-groups of CI users or between each sub-group and controls for the visual task (Fig. 2). Each sub-group of patients as well as controls relatively accurately reproduced visual standards up to approx. 2 s and underestimated standards of longer durations.

To summarize, CIuPC, reproduced auditory standards of shorter durations (from 1 to 2.5 s) less accurately than CIuGC and normally hearing subjects. It should be stressed that these deficits were observed only for the impaired auditory modality, whereas we did not observe the above differences for the intact visual modality.

DISCUSSION

A typical pattern of relationships (i.e., the relatively accurate reproduction of standards up to a few seconds and the under-reproduction of longer ones) was observed for the visual task in both sub-groups of CI users and also in normally hearing subjects (Figs. 1, 2). Thus, for the visual task, patients, independently of their level of language ability, displayed a similar pattern of results as subjects with normal hearing. A different pattern of results was observed for the auditory task. Although for the whole group of patients their performance was similar to that observed in controls, a significant decrease in the accuracy of reproduction accompanied comprehension deficits in CI users. Specifically, CIuPC over-reproduced shorter auditory standards (from 1 to 2.5 s, Fig. 1). In contrast, the performance of CIuGC did not differ from that of controls.

The typical pattern of reproduction mentioned above can be explained by referring to Pöppel's model of time perception (Pöppel 1994, 1997). Accordingly, the relatively accurate reproduction of short standards (up to a few seconds) can be explained by postulating the existence of a specific TI mechanism (see Introduction). Our results show that the typical functioning of this mechanism was observed in controls and in CIuGC for both modalities (Fig. 2), but it seemed to be disordered in CIuPC for the auditory task (Fig. 1).

On the other hand, different processes may be responsible for the observed underestimation. According to Block and Zakay (1996) and Block et al. (1999), because of impatience, subjects allocate more attention to time during reproduction of relatively long standards. Focusing on the time when the duration will end may result in shorter reproductions. This strategy seems to have a similar influence on all three groups.

To explain the less accurate reproduction of short auditory standards by the CIuPC subgroup, we can refer to a hypothesis explaining the nature of the overestimation of short intervals in prospective time judgment. Block and Zakay have shown that attention influences the accuracy of time reproduction (Block and Zakay 1996, Block et al. 1999, Zakay and Block 1996, 1997). Specifically, the attentional-gate model suggests that during time estimation, temporal units are produced by a pacemaker and stored in a reference memory. Subjects may divide their attentional resources between attending to time and attending to external nontemporal events, which influences the number of pulses accumulated. If the concurrent nontemporal task is performed during the reproduction of the previously presented interval, more time is necessary to accumulate the proper number of pulses (the pulse count in working memory should be equal to that in reference memory), which results in over-reproduction. Although in the present experiment no concurrent nontemporal tasks were applied, it may be assumed that, to some extent, pressing on the button when a subject experienced that the duration of the standard was reached might have some distracting influence. Such a motor task requires planning and preparation for a movement and, next, pressing the button. In the case of short standards, these nontemporal motor processes consumed proportionally more time during the reproduction phase than in the case of longer standards (above 3 s). Therefore, their influence seems to be specially pronounced for the case of shorter standards. Additionally, for longer standards such an influence seems to be reduced by the subject's impatience when in a situation requiring waiting (see above).

An alternative explanation of over-reproduction is based on the hypothesis developed by Fortin et al. (1999) and concentrates on the role of working memory. These authors assumed that performing concurrent tasks (which engage working memory) during temporal reproduction leads to overestimation. Referring to the present experiment, the concurrent nontemporal task (pressing the button) that engaged working memory could result in over-reproduction in a similar way as described in case of the attentional-gate model (Block and Zakay 1996, Block et al. 1999, Zakay and Block 1996, 1997).

The question arises as to why the over-reproduction of standards from 1 to 2.5 s was only observed in the auditory task in CIuPC, whereas, normally hearing subjects and CIuGC reproduced these standards relatively accurately (Fig. 1).

It is known that people have both limited attentional resources and working memory capacity (e.g., Baddeley 1995, Siple 2000). Many activities can interfere with each other, as they require the same pool of resources. However, with time and practice some of these activities can become rearranged, restructured or automatic, which can reduce processing interference (Siple 2000). There is also some evidence that disorders within sensory systems can result in the restructuring of information processing. For example, deaf people may rely on the visual modality for more types of information than normally hearing people. This opens up the possibility of greater competition for limited attentional and working memory resources in the case of the visual system, although restructuring within sensory systems allows deaf people to function effectively. CIuPC may also benefit from the restructuring of information processing. It is possible that a distorted signal from an implant is not informative enough and can not be relied on. As a result, the primary source of information for CIuPC is the visual modality, thus they rely more on visual information than CIuGC or normally hearing subjects do. CIuPC, for example, communicate mainly by lip-reading because they are able to understand only a small percent of speech through the auditory channel. As a result, more attentional and working memory resources are engaged in processing visual information. Taking into account that people have a limited pool of attentional and working memory resources, more of these resources engaged in one type of sensory processing can result in fewer resources for the remaining sensory processing. As a consequence the auditory channel in CIuPC may become less effective than the visual one, thus, it would be easier to interrupt auditory information processing by a concurrent nontemporal task. Probably for this reason we observed the over-estimation of shorter standards in CIuPC only for the auditory modality (Fig. 1), whereas, for the visual modality a similar pattern of performance as for that in normally hearing subjects and CIuGC was observed (Fig. 2).

The more effective processing of visual information in CIuPC could theoretically result in a higher accuracy of reproduction of shorter visual standards in comparison both with CIuGC and normally hearing subjects. The lack of significant group differences may be due to the relatively accurate reproduction of these standards in all three groups, thus CIuPC did not have the possibility to demonstrate significantly improved performance (a ceiling effect).

The previous discussion indicates that cognitive factors can influence time perception on the level of a few seconds. To sum up, for the CIuPC tested in our study, temporal information processing was disordered for the impaired auditory modality, whereas it remained unimpaired in the intact visual modality. Thus, the temporal deficits reported here have a strong modal effect. Deficits in auditory temporal processing on the level of a few seconds may influence the other processes in which this range is critical. One possible example of these processes could be language functioning, especially for the perception of segments which last a few seconds, such as words and strings of words – phrases. Thus, the deficits described above can modify the functioning of the TI mechanism in CIuPC. It could be one of the reasons for poor speech understanding in CIuPC. However, the temporal processing deficits reported here may coexist with those on other temporal levels, related to the perception of phonemes (i.e., a time domain of some tens of milliseconds). The results of our earlier studies (Kanabus et al. 2003) indicate the possibility of deficits in CI users for these levels.

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