Effects of Minimum Stimulation Settings for the Med El Tempo+ Speech Processor on Speech Understanding

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Objective: **The aim of this study was to assess the effects of variations in the settings for minimum stimulation levels on speech understanding for adult cochlear implant recipients using the Med El Tempo+ speech processor.**

Design: **Fifteen patients served as listeners. The test material included sentences presented at a conversational level in noise (74 dB SPL at +10 dB signal-to-noise ratio), sentences presented at a soft level in a quiet background (54 dB SPL), consonants in "vCv" environment (74 dB SPL re: vowel peaks), and synthetic vowels in "bVt" environment (54 dB SPL re: vowel peaks). The patients' speech processors were programmed with minimum stimulation levels set to behavioral threshold, set to 10% of most comfortable loudness, and set to 0 μA.**

Results: **The level of speech understanding achieved in the behavioral threshold condition was not significantly different from that achieved in either the 10% of most comfortable loudness or 0 μA conditions for any test material. Only 2 of the 15 patients demonstrated performance differences of greater than 10 percentage points between the 0 μA condition and the behavioral threshold condition on more than a single test.**

Conclusions: **Our results demonstrate that there are no grievous consequences, in terms of speech understanding, for setting minimum stimulation levels below behavioral thresholds. The time savings from setting thresholds to 10% of MCL or 0 μA may be especially useful during the initial device fitting.**

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A time-consuming aspect of fitting a cochlear implant to a patient, particularly a pediatric patient, is the setting of minimum and maximum stimulation levels on each electrode. Minimum stimulation levels are usually set to behavioral threshold, or the level that produces a barely audible percept. Maximum stimulation levels are usually set to produce a comfortably loud percept, commonly referred to as the most comfortable loudness (MCL) level.

Recently, it has been suggested that the fitting process can be streamlined by eliminating the assessment of behavioral thresholds (Kühn-Inacker et al., 2002). In the streamlined process, minimum stimulation levels are set to 0 μA or to 10% of the MCL on each electrode. There are two significant consequences of this fitting strategy. One is a reduction in programming time. The other is that the smallest amplitude signals acquired by the device will be represented by subthreshold electrical signals and will be inaudible to the listener. The value of a streamlined fitting process hinges on the amount of information lost when low-level signals are mapped to values below behavioral threshold.

The amount of information lost will depend on the input dynamic range of the device and the nature of the function that maps the input signal into a patient's electrical dynamic range. The Med El Corporation Tempo+ speech processor used in the current experiment captures a 75 dB range of input levels and maps 55 dB of that range into a patient's electrical dynamic range using a logarithmic compression function (Stöbich, Zierhofer, & Hochmair, 1999). This function is shown in Figure 1. The *x* axis is dB, so the logarithmic compression function appears as a straight line. Three starting points for the function are illustrated: behavioral threshold, 10% of MCL, and 0 μA. All starting point values are mean values from patients in the research to be reported here. Visual inspection of the three functions suggests that in the conditions where minimum stimulation levels are set below behavioral threshold there will be (1) a small reduction in the loudness of the signal, depending on where the input signal falls in the sound window, and (2) a loss of low-amplitude signals: 4 dB when the minimum stimulation level is set to10% of MCL and 9 dB in the case of 0 μA.

It is unlikely that a loss of 4 to 9 dB of a 55 dB input dynamic range would have a significant effect on the perception of speech. To determine whether this is the case, we assessed speech understanding in 15 patients fitted with the behind-the-ear version (Tempo+) of the Med El Corporation cochlear implant system when minimum stimulation levels were set conventionally (i.e., equal to behavioral thresholds) and when minimum stimulation levels

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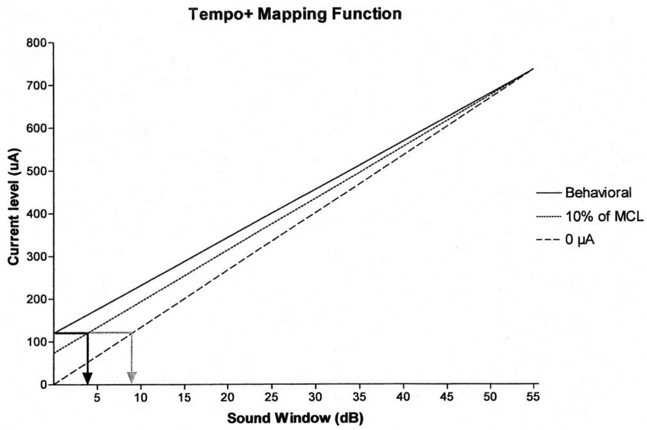

Fig. 1. Three input compression functions for the Tempo+ speech processor. Functions are shown for three minimum stimulation level settings: 120 μA for the behavioral condition, 73.6 μA for the 10% of most comfortable loudness (MCL) condition, and 0 μA for the 0 μA condition. Arrows indicate the range of output levels mapped below behavioral thresholds for the10% of MCL (black) and 0 μA (gray) conditions.

were set in a streamlined fashion (i.e., equal to 0 μA or 10% of MCL). To obtain a broad view of patient performance, sentences, consonants, and vowels were used as signals. The sentences were presented in noise and at low input levels.

METHODS

Subjects

Fifteen subjects implanted with the Tempo+ cochlear implant system participated in this study. All were experienced users of the Tempo+ speech processor. Consonant Nucleus Consonant (CNC) scores for the group ranged from 54 to 94% correct.

Test Material

The test material included sentences, vowels, and consonants. The sentence material consisted of 6 lists of 40 sentences recorded by 2 male and 2 female speakers. The sentences were produced in a conversational style by untrained speakers. The lists were of equal intelligibility (89% correct) when passed through a simulation of a 5-channel, cochlear implant signal processor and presented to normal-hearing listeners (Spahr & Dorman, 2004). The assignment of a list to a condition was randomized for each subject. Sentences were presented at 74 dB SPL at +10 dB signal-to-noise ratio (4-talker babble) and at 54 dB SPL in quiet.

The vowel stimuli were 13 vowels in "bVt" format (Dorman, Dankowski, Smith, & McCandless, 1989). The stimuli were synthesized by using the KLATT algorithm. The vowels were brief (90 msec) and of equal duration. Thus, vowel length was not a cue to identity. There were 5 repetitions of each stimulus. The order of the items was randomized in the test list. Signal level was 54 dB SPL re: vowel peaks.

The consonant stimuli included 20 consonants recorded in "eCe" format, e.g., "a bay," "a day," "a gay," and so forth. A single male talker produced each "eCe" 5 times. The pitch and vocalic portion of each token was intentionally varied so that pitch or vowel quality would not be systematic cue to consonant identity. The order of items was randomized in the test list. Signal level was 74 dB re: vowel peaks.

Processor Settings

The microphone sensitivity for the Tempo+ system is 75 dB. The system uses a 55 dB sound window that adjusts automatically, based on the input signal, and that maps the input signal to a patient's electrical dynamic range.

For each patient, two new signal processing programs were created. If a patient's everyday processor used behavioral threshold for the minimum stimulation level, then programs were created by using 10% of MCL and 0 μA. If a patient's everyday processor used 10% of MCL as the minimum stimulation level, then programs were created by using behavioral threshold and 0 μA. In all instances, only minimum stimulation levels were varied across programs. Behavioral thresholds were measured or verified for all patients on all electrodes by adjusting the stimulation level to produce a barely audible percept. MCL levels were verified as being comfortably loud on all electrodes. Due to time limitations, sound field thresholds were not obtained.

Procedures

Test order was randomized for each subject. For each type of test, the condition order (i.e., the order of testing with minimum stimulation levels set to behavioral threshold, 10% of MCL or 0 μA) was also randomized. Subjects were given a short practice period before all tests in all conditions. All testing was completed within a single session. Subjects were not given feedback on performance until participation in the study was concluded.

RESULTS

The group-mean percent correct scores from each test condition are shown in Figure 2. Repeated-measures analyses of variance (ANOVAs) revealed that manipulations of the minimum stimulation level settings had no significant effect on sentence identification at 54 dB SPL in quiet (behavioral

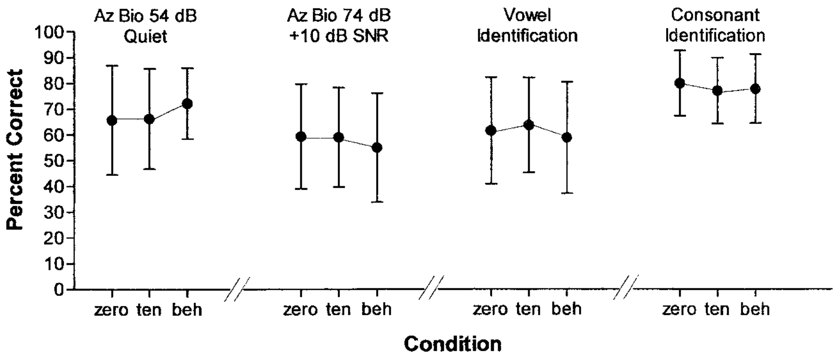

Fig. 2. Mean percent correct scores for test material as a function of minimum stimulation level settings. Minimum stimulation levels were set to 0 μA (zero), 10% of most comfortable loudness (MCL) (ten), or to behavioral thresholds (beh). Error bars indicate ±1 SD.

threshold = 72%, 10% MCL = 66%, 0 μA = 66%; $F_{(2,14)} = 2.42$, $p = 0.11$) or at 74 dB SPL at +10 signal-to-noise ratio (behavioral threshold = 55%, 10% MCL = 59%, 0 μA = 59%; $F_{(2,14)} = 2.74$, $p = 0.08$), on vowel identification (behavioral threshold = 59%, 10% MCL = 64%, 0 μA = 59%; $F_{(2,14)} = 1.57$, $p = 0.23$), or on consonant identification (behavioral threshold = 78%, 10% MCL = 77%, 0 μA = 80%; $F_{(2,14)} = 2.12$, $p = 0.14$).

Consonant scores were analyzed further by using information transfer scores for the features place, manner, and voicing (see Fig. 3). Repeated-measures ANOVAs revealed no significant effect of minimum stimulation level for place of articulation (behavioral threshold = 64%, 10% MCL = 62%, 0 μA = 65%; $F_{(2,14)} = 0.61$, $p = 0.55$) or manner of articulation (behavioral threshold = 89%, 10% MCL = 88%, 0 μA = 91%; $F_{(2,14)} = 2.33$, $p = 0.12$). A significant effect was found for voicing ($F_{(2,14)} = 3.97$, $p = 0.03$). A post hoc Scheffé test revealed significantly higher scores in the 0 μA condition (83% correct) compared with the 10% of MCL condition (75% correct). The 0 μA condition did not differ from the behavioral threshold condition (79% correct).

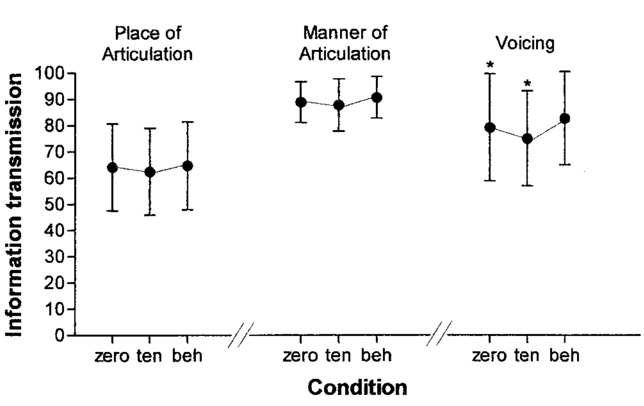

Fig. 3. Group mean data for consonant feature identification as a function of minimum stimulation level settings. Minimum stimulation levels were set to 0 μA (zero), 10% of most comfortable loudness (MCL) (ten), or to behavioral thresholds (beh). Error bars indicate ±1 SD. Asterisks indicate a significant difference between conditions ($p < 0.05$).

Inspection of individual patient outcomes revealed that only 2 of the 15 patients demonstrated performance differences of greater than 10 percentage points between the 0 μA condition and the behavioral threshold condition on more than a single test. The scores for each patient, averaged over all test material, are shown in Figure 4 as a function of the minimum stimulation level setting. At issue was whether performance was best for the minimum stimulation level with which patients were most accustomed. Approximately half of the patients (N = 7) had chronic experience with a minimum stimulation level set to behavioral threshold, and half (N = 8) had chronic experience with the 10% of MCL setting. A repeated-measures ANOVA revealed no significant difference between minimum stimulation settings for either the group with chronic exposure to behavioral threshold condition (behavioral thresholds = 58%, 10% of MCL = 58%, 0 μA = 60%, $F_{(2,6)} = 0.6$, $p = 0.56$) or the group with chronic exposure to the 10% of MCL setting (behavioral thresholds = 73%, 10% of MCL = 74%, 0 μA = 73%, $F_{(2,7)} = 0.22$, $p = 0.8$).

DISCUSSION

The aim of this study was to assess the effects of minimum stimulation levels on speech understanding for adult patients fitted with the Med El Tempo+ cochlear implant system. For sentences presented at low levels and in noise for consonants and for vowels, patient performance was unaffected by the settings for the minimum stimulation levels. This outcome is reasonable given the small amount of signal lost when the minimum stimulation levels are set below behavioral threshold. We have no account for the small and variable effect of minimum stimulation level on the perception of consonant voicing.

Approximately half of our subjects had chronic experience with minimum stimulation levels set to 10% of MCL and half had chronic experience with minimum stimulation levels set equal to behavioral

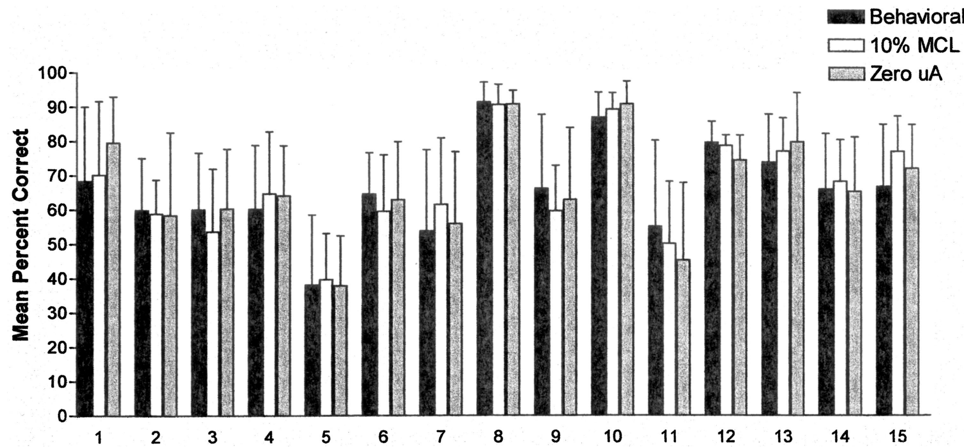

Fig. 4. Individual bars represent the mean score from all test material for minimum stimulation levels equal to 0 μA (dark gray), 10% of most comfortable loudness (MCL) (light gray), or behavioral thresholds (black). Before testing, subjects 1 through 7 had chronic exposure to the behavioral thresholds condition and subjects 8 through 15 had chronic exposure to the 10% of MCL condition.

thresholds. No subject had experience with minimum stimulation levels set to 0 μA. It is reasonable to expect that subjects will perform at a higher level with a familiar program than with an unfamiliar program. However, we found no effect of a familiar program, that is, chronic experience, on performance.

Although the procedure used to set minimum stimulation levels did not significantly affect scores on any individual test of speech perception, the procedure did affect other aspects of auditory perception. Specifically, subjects reported signals to be slightly softer in the 10% of MCL and 0 μA conditions. This is reasonable, given the small change in the slope of the compression function shown in Figure 1. Subjects also reported that ambient noise was more audible when minimum stimulation levels were set to behavioral threshold. This is also reasonable, given the functions shown in Figure 1. From a clinical standpoint, minimum stimulation level settings may benefit patient satisfaction. For example, if a patient reports the audibility of soft sounds as undesirable, then setting minimum stimulation levels below behavioral threshold would be beneficial. If, however, the patient reports that soft sounds contain desirable information, then setting minimum stimulation levels below threshold would be counterproductive. Also, the importance of low-level inputs should not be overlooked for sound awareness or incidental learning in pediatric populations. However, it should be noted that the quality of soft environmental sounds may be compromised as the input level approaches the noise floor of the microphone. Thus, increasing minimum stimulation levels to behavioral thresholds to improve the audibility of soft sounds may not be beneficial in all cases. In our experience, some patients prefer to hear "background" sounds. Others do not. Whichever the case, we find no evidence to suggest grievous consequences in terms of speech understanding for setting minimum stimulation levels below behavioral thresholds in an attempt to streamline the programming process and to provide an initial map to a patient.

We find no significant loss of speech intelligibility when minimum stimulation levels are set below behavioral threshold. Might speech intelligibility improve if minimum stimulation levels were set above behavioral threshold? On the one hand, the audibility of low-level signals would be improved. This could improve speech intelligibility, provided the low-level signals contained critical acoustic/phonetic information. The amount of critical, low-level information will depend on the input dynamic range of the signal processor. If the input dynamic range is small, then it may be useful to make sure that the smallest signals are significantly above the threshold of audibility. On the other hand, if minimum stimulation levels were set above behavioral threshold, ambient noise would be louder and the reduction in the patient's electrical dynamic range could minimize the perceptual difference between soft and loud sounds.

Skinner, Holden, Holden, & Demorest (1999) programmed a device with a limited (30 dB) input dynamic range, the Nucleus 22 system, using minimum stimulation levels set to behavioral threshold and set to a "raised" level above behavioral threshold (1.01 to 4.79 dB, depending on the patient). Skinner et al. (1999) found a small improvement, approximately 5 percentage points, in speech understanding in some test conditions when the raised minimum stimulation levels were used. As we noted above, it is not unreasonable, when working with a device with a limited dynamic range, to make the lowest level signals more audible. However, if a device has a large dynamic range, for example, the 55 dB sound window of the device used in this experiment, then there would seem to be little need to elevate minimum stimulation levels. Indeed, we find that with an adaptive 55 dB sound window the lowest level signals can be mapped below threshold without affecting speech understanding—at least for the test conditions we have used. However, clinicians may find that on an individual level, some patients require threshold adjustments to alter their perception of soft sounds. Further research should be conducted to determine how the subjective perception of real-world environments is affected by variations in the setting of minimum stimulation levels.

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