The Relationship Between Pulse Rate and Mandarin Tone Recognition: A Preliminary Study with CCi-Mobile Cochlear Implant Research Processor

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ABSTRACT

The aim of this study is to evaluate the effects of pulse rate (i.e., stimulation rate) on Mandarin tone recognition by cochlear implant users. Mandarin tone recognition was measured by using monosyllabic and disyllabic tone data-bases at three pulse rates in cochlear implant users. The three pulse rates included each participant's clinical default pulse rate (i.e., 900 or 1200 pulses per second (pps) for each electrode), 400 pps, and 200 pps. A real-time research speech processor, CCi-Mobile, was used to implement the signal processing strategies. Although the results are variable among participants, there was a trend that the recognition rates of both monosyllabic and disyllabic databases decreased with lower pulse rates, indicating that low pulse rates degrade acoustic cues, like periodicity, for Mandarin tone perception. This study also provided preliminary data for evaluating the CCi-Mobile research processor for the first time in China. The processor could be used for signal processing algorithm development and psychophysical experiments in the future.

CCS CONCEPTS

• **Applied computing**; • **Life and medical sciences**; • **Computational biology**;

KEYWORDS

CCi-Mobile, Pulse rate, Tone recognition, Cochlear implant

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1 INTRODUCTION

Cochlear implants (CIs) restore hearing to severely and profoundly deaf people by stimulating auditory nerve fibers mostly by using fixed-rate electric pulse trains. Pulse rate (stimulation rate) is defined as the number of electrical pulses that an electrode transmits per second, i.e., pulses per second (pps) per electrode. The pulse rate is an important parameter that needs to be adjusted during the clinical device fitting for CI users. Previous studies have investigated the effects of pulse rate on speech perception [1-4]. However, most studies focus on the phonetic contrasts between consonants and vowels, and the effects of pulse rate on the recognition of lexical tones in a tonal language has not been fully investigated yet.

In tonal languages, such as Mandarin and Cantonese, tone recognition is important for listeners to understand the meanings of words. Tone recognition plays an important role in everyday communications of CI users who are tonal language speakers [5-7]. In Mandarin Chinese, there are four typical tones characterized by the fundamental frequency variation. Previous studies have explored the ability and mechanism of tone recognition with CIs. All evidences support that tone perception in CI users is much poorer and more variable than in normal hearing (NH) listeners, especially under adverse conditions. This is partly because of the imperfect pitch coding in CI systems [8]. Pitch cues can derive tone recognition with CIs as well as with NH listeners. There are some secondary cues that can also facilitate CI tone recognition, such as the amplitude contour (or loudness contour) and duration [9-12].

Au (2003) studied the effects of stimulation rates (400, 800, and 1800 pulse-per-second, pps) on Cantonese lexical tone perception

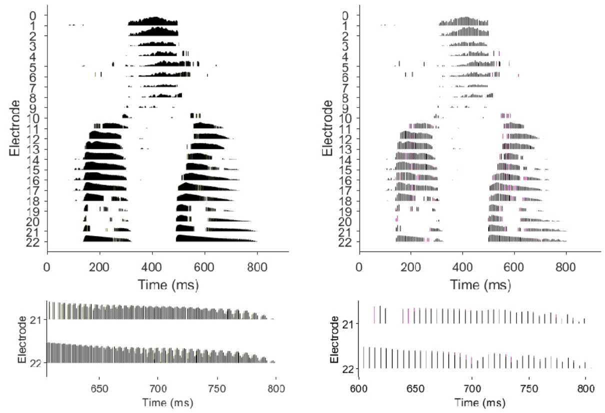

Figure 1: Electrodograms of a stimulus 画像(portrait) /huà xiàng/ at pulse rates of 900 (left) and 200(right) pps. The upper panels show the entire electrodogram, while the lower panels show a magnified portion of the stimulation on electrodes #21 and #22 (low-frequency electrodes).

by CI users using the Continuous Interleaved Sampling (CIS) strategy in Hong Kong, which found that the higher stimulation rate, the better perception of Cantonese lexical tones [13]. Fu et al. (2004) studied the effects of speech processing strategies on Chinese tone recognition by Nucleus-24 CI users and found that for the Advanced Combination Encoder (ACE) strategy, there was no significant difference in performance among various stimulation rates (900, 1200, 1800 pps) [14]. These pulse rates are relatively high, as most CI users use a pulse rate of 900 or 1200 pps, thus, the effects of relatively low pulse rates on Mandarin tone recognition remain unclear. And it is difficult to evaluate their ability to use acoustic cues at different pulse rate, due to most clinical devices use fixed pulse rate [15].

The present work studies the effects of relatively low pulse rates on Mandarin tone recognition by CI users. Three different pulse rates (participant's default pulse rate, 400 and 200 pps) were tested in this study. The pulse rates of 400 and 200 pps were selected as samples of low pulses rates. As mentioned above, most CI users use a pulse rate of 900 or 1200 pps. Electrodograms of one stimulus used in the experiment with pulse rates of 900 and 200 pps are demonstrated in Figure 1. From the upper panels, it can be observed that the overall stimulations on each channel are much sparser at 200 pps. From the lower panels, it can be observed that stimulations on electrodes #21 and #22 show obvious temporal periodicity at 900 pps while nearly no periodicity could be observed on the two electrodes at 200 pps. This effect could cause lower recognition rates at lower pulse rates, which is one of the reasons why we made a hypothesis that lower pulse rates like 400 and 200 pps will cause lower Mandarin tone recognition scores. To test this hypothesis, an experiment was carried out using a CCi-Mobile research processor. Lexical tone recognition performance of CI users was evaluated at three different pulse rates including participant's default pulse rate, 400 and 200 pps. Performance using participants' clinical devices was also tested as a baseline.

2 CCI-MOBILE RESEARCH PROCESSOR

One major obstacle in the way of many CI researchers is that even when they have developed new sound processing algorithms for CIs, they are often unable to assess their new algorithms in actual CI users [16]. To make a CI user hear a sound, a processor is needed to receive the sound, process it using some algorithms, and at last convert the processed sound into radio-frequency (RF) signals that the implant can receive and generate electrical stimulations. CI users rely on their sound processors for hearing, but their processors are not open for implementation of new algorithms. A research processor is a processor that makes it possible for professional researchers to implement new algorithms. Without it, it would be very difficult to assess a new algorithm in actual CI uses. Instead, some researchers used vocoders in normal hearing listeners to simulate the hearing of CI users [17-19], but the implications of vocoder simulation for CIs remain controversial. To enable flexible tests outside a lab, it would be ideal if a research processor could be portable and allows real-time processing.

The CCi-Mobile research processor is an open-source research platform developed by the CRSS-CI Lab at the University of Texas at Dallas [20]. It now supports experiments with CI users using products from the Cochlear company. It picks sounds from two Behind-the-Ear (BTE) microphones, samples digitally by an on-board stereo codec, then sends to a PC or smartphone for processing using the Advanced Combinational Encoder (ACE) strategy or any customized strategies via USB-serial port. After processing, the stimulation signal is sent back to the platform and is finally streamed to the implants for stimulation. This process works in real-time loops.

Table 1: Participant demographic data

Participant	Gender	Age	CI Experience	Implanted side	Tested side	Default pulse rate (pps)
C28	F	40	12	L&R	R	900
C58	M	29	11	L	L	1200
C2	M	25	16	L	L	900

3 METHODS

3.1 Materials

In this experiment, tone recognition was tested using materials from a monosyllabic and a disyllabic database. The monosyllable database (denoted by "Mono") [21] consists of 100 monosyllable tokens naturally produced by a female speaker. These 100 tokens include 25 consonant-vowel combinations with each having four tonal patterns, for example, (e.g., /mā/, /má/, /mǎ/, and /mà/). The disyllable database (denoted by "Di") (as demonstrated in [22]) consists of 270 disyllabic words resynthesized from 10 recorded disyllabic words, including recordings of both a female and a male speaker naturally producing 5 disyllabic words, i.e., /Lǎo Shī/, /Róng Huā/, /Shè Jī/, /Píng Fāng/, and /Huā Xiāng/. The second syllables of the first four disyllabic words and both syllables of the fifth disyllabic word were manipulated to have 9 different pitch contours (3 flat contours, 3 rising contours, and 3 falling contours) and 3 different loudness contours (flat, rising, and falling), which makes 27 pitch-loudness-contour combinations. The Mono database is naturally produced material, including multiple tone cues covarying with each other, while the Di data-base is artificially manipulated material whose pitch and loudness contours are independently varying. Therefore, Di tone recognition should be more difficult than Mono tone recognition.

3.2 Participants

We tested this hypothesis in three bilaterally deaf participants who are native Mandarin speakers. They use devices from the Cochlear company with the ACE strategy. Participants were paid for their time and travelling expense, and all provided informed consent before the experiments. Table 1 lists the participant demographic information.

3.3 Procedure

The experiment composed of a pre-test and a formal tone test. The pre-test was conducted before the formal tests to get the sentence perception performance of each participant using their clinical devices and CCi-Mobile, both at their default pulse rates. Sentence perception performance was measured by using a Mandarin BKB-like sentence corpus in which each list consists of 10 sentences [23]. Sentences were presented to the participants in a random order, and the participants were asked to repeat what they hear orally. The number of correct words was recorded, and a percent correct score was calculated. Different lists were used for the participants' clinical devices and CCi-Mobile to avoid familiarity with the sentences.

In the formal test, Mandarin tone recognition performance was measured using materials from Mono and Di at three different pules rates, i.e., participant's default pulse rate, 400 and 200 pps. The default pulse rate was tested on both the clinical processor and the CCi-Mobile research processor, while the pulse rates of 400 and 200 pps were tested only on the CCi-Mobile research processor. Therefore, there were 4 pulse rate-device combinations, and both Mono and Di were tested under each combination, which made 8 test blocks in total. The order of these 8 test blocks was randomized. To shorten the test duration and avoid participant fatigue, each Di block used half of the 270 words. Thus, there were 135 trials for each Di block and 100 trials for each Mono block. In each trial, the participant was asked to determine the tone perceived by selecting written words on a computer screen with a mouse. A 4-alternative-forced-choice (4AFC) task and a 3AFC task were used for Mono and Di, respectively. A word was scored as correctly identified when the participant chose the choice with the meaning of the word that corresponds to the lexical tone given by the pitch contour. No feedback was given to the participant during the test. Stimuli were presented at a comfortable level (approximately 65 dBA) through a soundcard (TASCAM US-322) and a loudspeaker (YAMAHA HS5) located in front of the participant in a soundproof room (background noise no more than 30 dBA).

4 RESULTS

Figure 2 shows the sentence recognition result of the pre-test before the formal tone tests. C28 scored 95.4% and 92.3% when tested using their clinical devices and CCi-Mobile, respectively. C58 scored 96.4% and 94.4%, and C2 scored 79.5% and 53.7%.

Formal tone recognition test results are shown in Figure 3. The dotted lines de-note the chance levels and the bars show the participant scores. Since 4AFC tasks were used for Mono and 3AFC for Di, the chance levels for Mono and Di were 25% and 33.3%, respectively. All three participants performed above the chance level in Mono, and C2 performed below the chance level at the pulse rate of 400 pps.

Among the three participants, C28 finished all 8 blocks and the other two participants finished parts of the test. C58 reported that he could not hear words clearly at pulse rates of 400 and 200 pps, and neither could C2 at 200 pps. Those blocks were not tested thus no data were collected for those blocks.

The results of Mono are shown in the left panel in Figure 3. C28 got her highest score using her clinical device, followed by the CCi-Mobile at her default pulse rate of 900 pps, then 400 pps, and lowest at 200 pps, (84%, 56%, 48%, and 40%, respectively). C58 scored 78% and 47% at his default pulse rate of 1200 pps using his clinical device and the CCi-Mobile, respectively. C2 performed best using his clinical device, worse using the CCi-Mobile at his default

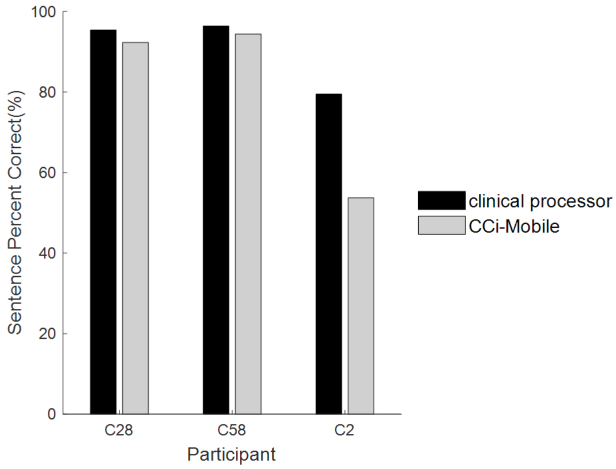

Figure 2: Sentence percent correct scores using participants' clinical processors and the CCi-Mobile research processor at each participant's default pulse rate.

pulse rate of 900 pps, and worst at 400 pps (87%, 53% and 33%, respectively).

All three participants showed similar performance trends in Di, as shown in the right panel in Figure 3. C28 scored 76%, 63%, 59%, and 41% using her clinical device, the CCi-Mobile at her default pulse rate of 900 pps, 400 pps, and 200 pps, respectively. C58 got 81% and 67% at his default pulse rate of 1200 pps using his clinical device and the CCi-Mobile, respectively. C2 had 67%, 41%, and 30% for his clinical device, the CCi-Mobile at his default pulse rate of 900 pps, and 400 pps, respectively.

5 DISCUSSION

This work aims to study the effects of relatively low pulse rates on Mandarin tone recognition by cochlear implant users by using a CCi-Mobile CI research processor. A pre-test was conducted to get the sentence perception performance of each participant and a formal test was administered to measure participants' lexical tone recognition performance at different pulses rates.

In the pre-test, 2/3 participants had quite close performances when tested using their clinical devices and the CCi-Mobile. This provided evidence that the CCi-Mobile indeed can work as a sound processor for converting sound to electrical signal codes, such that the two participants can perform closely with the two kinds of devices.

In the formal tone recognition test, although the results were variable among participants, a trend can be observed that percent correct scores of both Mono and Di decreased with the decrease of the pulse rate. All three participants achieved their highest score when using their own clinical devices at their default pulse rate of 900 or 1200 pps, followed by CCi-Mobile at their default pulse rate, then 400 pps if tested, and lowest at 200pps (if tested). This observation may support the hypothesis that lower pulse rates like 400 and 200 pps will cause lower Mandarin tone recognition scores. This trend is also reported by Au (2003), who studied the effects of stimulation rates (400, 800, and 1800 pps) on Cantonese lexical tone perception by CI users with CIS strategy.

We also noticed that there was a gap of approximately 20% between the two kinds of devices in one participant in the pre-test. Gap between the two kinds of de-vices also existed in the formal tone recognition test. Even at their default pulse rates, all the three participants performed worse with CCi-Mobile compared to their clinical devices, where the scores were approximately 30% lower for Mono and 20% lower for Di. This gap indicates that further work

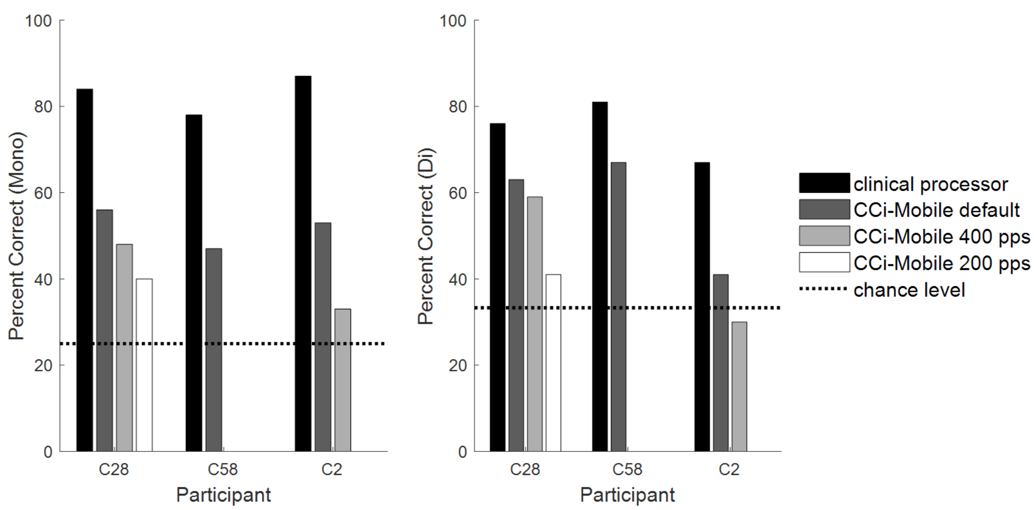

Figure 3: Percent correct scores of monosyllabic words(left) and disyllabic words(right) for participants' clinical processors and the CCi-Mobile research processor at each participant's default pulse rate, 400 pps and 200 pps. Two participants (C58 and C2) reported that they were unable to hear words clearly at the first or second lowest pulses rates; therefore, those data were not collected.

needs to be done to optimize the experiment protocol including clinical fitting and new strategy training.

6 CONCLUSIONS

The effects of pulse rate on Mandarin tone recognition by CI users were evaluated using the CCi-Mobile research processor in this study. Recognition scores of both monosyllabic and disyllabic words decreased with the decrease of the pulse rate from default 900 or 1200 pps to 400 and 200 pps.

To our best knowledge, this preliminary study is the first experiment using the CCi-Mobile research processor in China to test actual CI users. At least, the processor indeed works as a sound processor for converting sound to useful electrical signal codes, although further work needs to be done to optimize the experiment protocol including clinical fitting, new strategy training, and more patients.

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