The Haptic Chair as a Speech Training Aid for the Deaf

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ABSTRACT

The 'Haptic Chair' (Nanayakkara et al., 2009, 2010) delivers vibrotactile stimulation to several parts of the body including the palmar surface of the hand (palm and fingers), and has been shown to have a significant positive effect on the enjoyment of music even by the profoundly deaf. In this paper, we explore the effectiveness of using the Haptic Chair during speech therapy for the deaf. Based on evidence we present from a 12-week pilot user study, a follow-up 24-week study with 20 profoundly deaf users was conducted to validate our initial observations. The improvements in word clarity we observed over the duration of these studies indicate that the Haptic Chair has the potential to make a significant contribution to speech therapy for the deaf.

Author Keywords

Haptic feedback, Speech therapy

ACM Classification Keywords

K.4.2 Computers and Society: Social Issues–Assistive technologies for persons with disabilities; H.5.2 Information Interfaces and Presentation: User Interfaces–Haptic I/O; H.1.2 Models and Principles: User/Machine Systems–Human factors

INTRODUCTION

In our previous work, we developed a 'Haptic Chair' to enhance the musical experience of the Deaf using vibrotactile feedback (Nanayakkara et al., 2009, 2010). The Haptic Chair received very positive feedback from students at the Dr. Reijntjes School for the Deaf (www.schoolforthedeaf.lk) where it was tested. During these earlier user studies, it became apparent that the Haptic Chair had the potential to be a useful tool in speech therapy – going beyond the original aim of enhancing the pleasure of 'listening to music'.

Speech therapy is a treatment for people with speech and communication disorders resulting from a wide range of medical conditions such as cleft lip, weak muscles around the mouth, to hearing impairment, etc. The therapy sessions may include oral-motor exercise, speech drills to improve clarity of voice, or sound production practice to improve the patient's verbal articulation.

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OZCHI'12, November 26–30, 2012, Melbourne, Victoria, Australia.
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In this study, we focus on the speech therapy session for profoundly deaf children in Dr. Reijntjes School for the Deaf, Colombo, Sri Lanka where students are taught in Sinhalese. In a typical speech therapy session at the school, a deaf student and a speech therapist sit in front of a mirror. The student watches the speech therapist's lip movement in the mirror and tries to mimic those movements. We observed that the students are often able to mimic lip movements, but either they generate no sound or they generate sound very different from the example provided by the therapist. This is not surprising given the lack of audible feedback. Furthermore, it was also clear that many profoundly deaf students did not enjoy the speech therapy sessions, which is a common problem worldwide.

In this paper, we explore ways to make the speech therapy sessions both more effective and more enjoyable for the students. Since many deaf children at the school already regularly engaged with the Haptic Chair for listening to music, we wanted to explore the possibility of using it in speech therapy sessions. Almost a century ago, Gault (1926) proposed a method of presenting speech signals *via* a vibrator placed on the skin. This provided further motivation for exploring this kind of vibrotactile feedback for speech therapy and education. The design of the Haptic Chair was extended so that users would be able to sense amplified vibrations produced by their own voice as well as others such as teachers or therapists. With this modification, we observed immediate effects on the awareness the profoundly deaf users had of whether they were matching the sound production pattern accompanying the lip movements they could see. Our results suggest that this kind of display can, to some extent, function as an effective substitute for the traditional 'Tadoma' (Reed et al., 1982) method of speech instruction wherein students touch the throat or lips of their teachers. It would also open up a range of approaches for speech therapy aids that are independent of or complementary to the physical presence of a human therapist.

The rest of this paper is organized as follows: Section 2 provides an overview of some of the related work. The next section gives a brief description of the Haptic Chair system. This is followed by a description of the pilot study and the follow-up study. The last section concludes the paper with an outline of our plans for future work.

RELATED WORK

There is a long history of research on the use of electronic speech training aids to improve speech therapy and a comprehensive overview of such devices can be found in

(Braeges et al., 1982). Recently, software applications have been developed to provide alternative forms of speech therapy. Examples include *SpeechViewer III* (www.synapsea daptive.com), *Tiga Talk* Speech Therapy Games (www. tigatalk.com) and *Speech Sounds on Cue* (www. bungalowsoftware.com). These tools provide visual feedback by transforming spoken words and sounds (phonetic sounds) into imaginative graphics or animations of lip-movements. Visual feedback is intended to reduce the need for constant guidance by a therapist. Our previous work has shown that visual feedback coupled with vibrotactile feedback might be a more effective additional sensory input (Nanayakkara et al., 2009, 2010).

Support for this concept is provided by Shibata (2001) who found that some deaf people process vibrations sensed *via* touch in the part of the brain used by most people for hearing. According to Kayser *et al*. (2005), tactile sensation stimulates the auditory cortex in addition to the somatosensory cortex. These findings provide one possible explanation for how profoundly deaf musicians can sense music, and how profoundly deaf people can feel vibrations with greater sensitivity. Reed (1996) demonstrated that with sufficient training, blind and deaf practitioners of the 'Tadoma method' are able to use tactile sensations to support speech and language processing. In the Tadoma method, the hand of the deaf-blind individual is placed over the face and neck of the person who is speaking such that the thumb rests lightly on the lips and the fingers fan out over the cheek and neck. From this position, the deaf-blind user can primarily obtain information about speech from vibrations from the neck and jaw, the movement of the lips and jaw, and less importantly from the airflow characteristics produced during speech. This series of studies by Reed illustrates that naturally occurring tactile sensations produced by sound can provide acoustic information to the hearing-impaired. Furthermore, Palmer (1997) developed a theory in which he claimed that the vibrations produced by low-pitched (low frequency) tones can be felt by body sensors in the feet, legs and hips; middle tones can be felt in the stomach, chest and arms; and high-pitched tones can be felt in the fingers, head and hair. This theory is consistent with the findings of the review on the tactile modality, carried out by the Army Research Laboratory, USA (Myles, 2007). The mechanism of providing a tactile sensation through the Haptic Chair is quite similar to the common technique used by deaf people, called 'speaker listening'. In speaker listening, deaf people place their hands or feet directly on audio speakers to feel vibrations produced by audio output. However, the Haptic Chair provides a tactile stimulation to most of the body simultaneously in contrast to 'speaker listening' where only one part of the body is stimulated at any particular instant and not necessarily within an optimal frequency range. As suggested Palmer (1997) different parts of the body plays an important role in picking up different vibrotactile frequencies. The current study was designed to determine the effectiveness of the use of the Haptic Chair in speech therapy sessions.

HAPTIC CHAIR

The concept underlying the Haptic Chair is to generate vibrotactile stimulation from audio signals, delivering them to different parts of the body through the chair without adding any additional artificial effects into this communications channel by signal-processing the original audio output. Among the reasons for our strategic decision not to manipulate the audio signal used for tactile stimulation is that we believe the role played by higher frequencies in tactile perception is important. Speech information is carried primarily in the frequency region from 300 to 3000 Hz (Rossing, 1990), which corresponds to the range of sensitivity found in one of our recent studies using complex signals and vibrotactile stimulation of the palmar surface of the hand (Wyse et al., 2012).

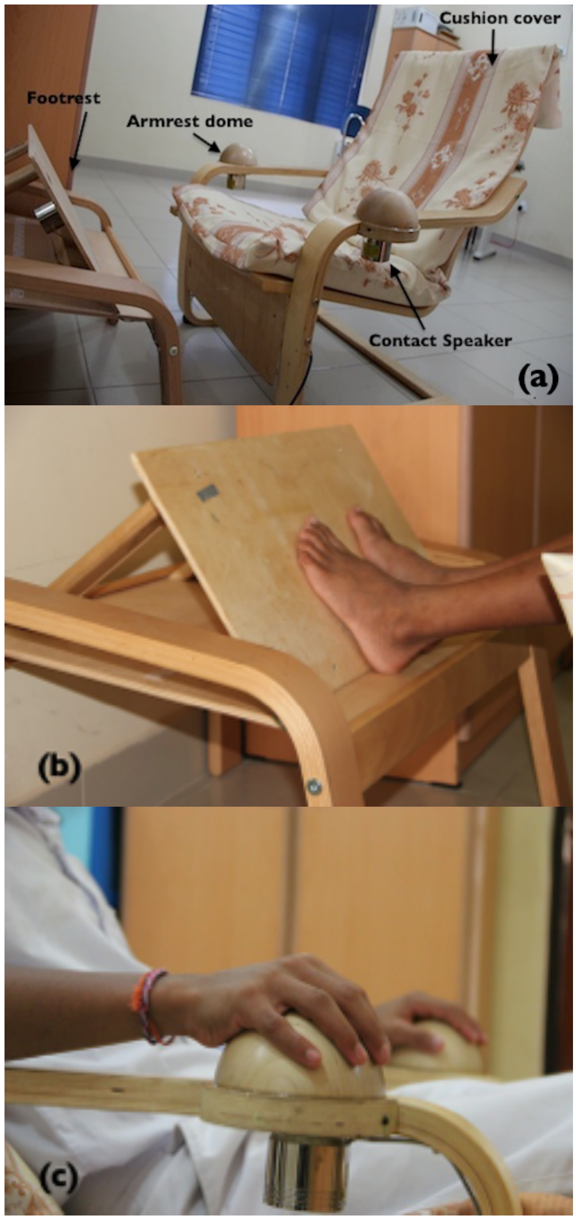

Figure 1: Haptic Chair. (a) Overview of the system. (b) Placement of feet on footrest. (c) Resting palm and fingers on the armrest domes.

A densely laminated wooden chair that is widely available ("Poäng" made by IKEA®) was used to develop the Haptic Chair. The frame of the chair is made of layer-glued bent beech wood, which provides flexibility, and solid beech cross-struts that provide rigidity. Contact speakers (SolidDrive™ SD1) were mounted under the armrests, footrest (also "Poäng" by IKEA), and on the backrest at the level of the lumbar spine (Figure 1). These contact speakers are designed to support the entire audio frequency spectrum, whereas typical vibrotactile actuators (inertial shakers, linear actuators, etc.) do not have such a broad frequency response (Mortimer et al., 2007). The quality and frequency response of the sound they produce is similar to that of conventional diaphragm speakers. This is important since many partially deaf people can hear some sounds via in-air conduction through the 'conventional' hearing route of the external ear canal.

A hollow wooden dome was mounted over each armrest to provide an ergonomic hand rest that brought fingertips, hand bones and wrist bones in contact with the vibrating structures in the main body of the chair (Figure 1c). A textured cotton cushion with thin foam insert was used to increase physical comfort while sitting in the chair but did not significantly interfere with haptic perception of music. It might have reduced bone conduction of sound, particularly to the skull, but since this was not the specific focus of the present study, the cushion was used because it increased the overall comfort of the user.

PILOT STUDY: PLACEBO EFFECT

Almost all the Haptic Chair users commented that the vibrotactile feedback gave an improved musical experience (Nanayakkara et al., 2009, 2010). In the context of speech, observations by the speech therapist who conducted these studies suggested that the deaf students were more vocal while using the Haptic Chair. However this could have been due to the mere psychological effect of sitting on a chair so different from their typical classroom chair. Therefore we conducted a pilot study to investigate the validity of the therapist's observation by: (1) comparing the effect of speech therapy using the Haptic Chair and standard speech therapy; (2) including a placebo treatment in which participants used the Haptic Chair in the 'OFF' condition (i.e. not delivering any vibrotactile stimulation). Participants in the placebo group might have thought that they were receiving some additional help from the Haptic Chair but actually were receiving no active effect.

Participants

Six profoundly deaf students (three boys and three girls; median age nine years ranging from six to ten years) took part in the study. All participants were profoundly deaf (four born deaf and two became deaf before the age of one year). These profoundly deaf children received regular speech training as part of Dr. Reijntjes School for the Deaf curriculum. An experienced speech therapist who had been working with the same group of children was present to conduct the study. All subjects were told that they could stop participating in the study at any time if they did not want to continue. This study was conducted in accordance with the ethical research guidelines provided by the Internal Review Board (IRB) of the National University of Singapore (NUS) and with IRB approval.

Procedure

The usual speech training sessions at the school use a system consisting of a mini-microphone, amplifier (Pocketalker® Model PKT C1) and headphones. The headphones were used in case the profoundly deaf participants still had some residual hearing. The speech therapist and the student sit next to each other looking in a mirror in front of them. The speech therapist holds a microphone and the student wears headphones. The sound from the microphone is amplified and sent to the headphones. As the speech therapist speaks, the hearing-impaired child hears the speech therapist's voice through the headphones and sees the lip movements in the mirror.

In this study we slightly modified the setting. An additional microphone connected to the same amplifier was used to capture the voice of the profoundly deaf user, which was then fed back to his/her headphone. With this, deaf users with residual hearing were able to hear the voice of the speech therapist as well as their own voice. But significantly, the sounds produced by both speech therapist and deaf user were used to generate vibrotactile feedback through the Haptic Chair.

Participants were divided into 3 groups: (1) *The Experimental group:* participants in this group received speech therapy while they were sitting in the Haptic Chair; (2) *The Placebo group:* participants in this group also received speech therapy while they were sitting in the Haptic Chair, however the chair was switched OFF and the children did not receive any vibrotactile feedback through the chair; (3) *The Control group:* participants in this group received speech therapy while they were sitting on the standard chair used by the speech therapist at the deaf school. All three groups received voice feedback through the headphones and visual feedback from the mirror. However, only the experimental group received the additional vibrotactile feedback through the Haptic Chair.

All participants in all three groups received speech therapy for one hour per day over a period of four weeks. At the end of each week, participants were asked to articulate ten common words used in Sinhala language. In order to make a fair comparison among the groups, this was done without using the Haptic Chair. The speech therapist judged the clarity of each of the spoken words on a continuous scale of 0 to 1. A very clearly spoken word was given a score 1 and a completely unclear word was given a score 0. Total score was used as the performance indicator. After the first four weeks, all six participants had a break of four weeks. The speech ability of each of the participants was re-assessed at the end of the forth week of the break. Subsequently, participants from all three groups were combined and given speech therapy with the aid of the Haptic Chair for another four weeks. As in the first four weeks, performance was assessed by the speech therapist on a weekly basis using the same ten words.

Results

Averaged performances of the groups are shown in Figure 2. All participants performed better with time. This is partly due to the familiarity they gain with the test word set as well as the instruction that is part of the therapy. During the first four weeks, both the placebo group and the control group showed similar rates of performance improvement. This suggests that there was no placebo effect—mean score of the group that used the Haptic Chair in the OFF state was similar to that of the control group. But, after the first four weeks, the rate of improvement of the experimental group was greater than that for the other two groups.

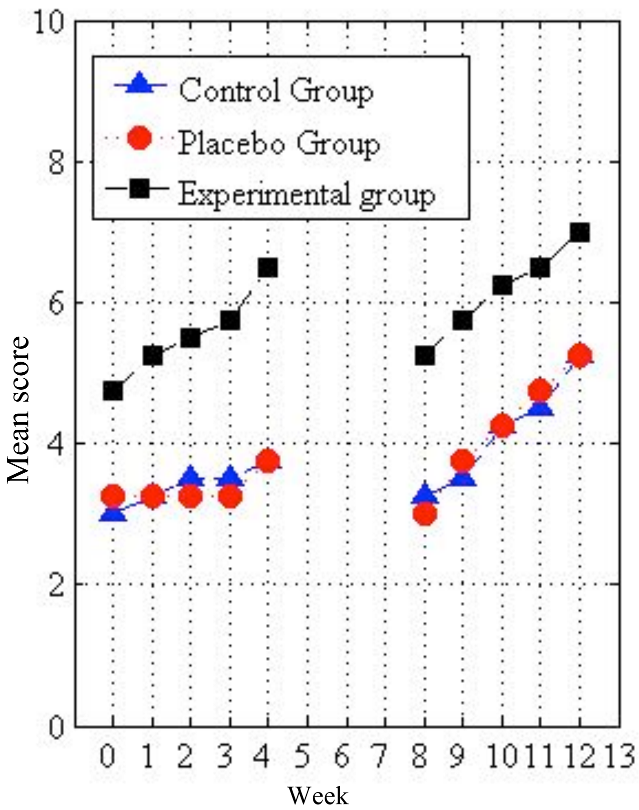

Figure 2: Pilot study: Average number of words recognized by the speech therapist after every week.

In this preliminary study, the experimental group happened by chance to have better speech ability even before the start of the study. Nevertheless, it can be seen that the experimental group's rate of improvement trends higher during the initial four weeks. The break of four weeks resulted in a significant drop in performance for the experimental group but it was still higher than performance at week 0. Experimental group picked-up from week eight onwards when they resumed speech therapy using the Haptic Chair. Compared with the first four-week block, the participants from the control group and the placebo group showed an increase in their rate of improvement when they began using the Haptic Chair from week eight. These observations suggest that the Haptic Chair had a positive influence on progress during speech therapy sessions.

FOLLOW-UP STUDY: HAPTIC CHAIR EFFECT

In view of the positive results of the pilot study but bearing in mind some potentially confounding factors, we conducted a more formal follow-up study to further investigate the effect of using the Haptic Chair during speech therapy sessions.

Participants

Twenty students (11 boys and nine girls; median age nine years, ranging from six to 11 years) from the same school took part in the study. All were profoundly deaf (eight born deaf, 11 were deaf before the age of one year, and one before the age of two years). They were not from the same group of participants who took part in the pilot study and therefore provided us with a fresh perspective. As in the pilot study, the school's speech therapist helped us conduct the study and the participants were told that they could stop taking part at any time. This study was also approved by the IRB of NUS.

Procedure

The procedure was very similar to the pilot study except that there was no placebo group. This decision was taken based on the pilot study results. The test cases consisted of 20 common words in Sinhala Language. Participants were asked to articulate the test cases (20 words) at the beginning of the study (week 0). As in the pilot study, the speech therapist judged the clarity of each of the spoken words. In addition, we asked an independent listener who was a native speaker of Sinhalese (a professional language instructor), to judge the clarity of each of the words. The speech therapist and the independent listener were in the same room while listening. However they were not allowed to discuss any kind of information regarding the evaluation. This helped mitigate any bias in the speech therapist's judgment. This initial assessment was used to divide the participants into two groups with similar speech abilities: (1) *The Experimental group:* received speech therapy while they were sitting in the Haptic Chair; and, (2) *The Control group:* received speech therapy while they were sitting on the standard chair used by the speech therapist at the deaf school. As in the pilot study, all the participants received voice feedback through headphones and visual feedback from the mirror. Only the experimental group received the additional vibrotactile feedback through the Haptic Chair. Participants from both groups received speech therapy for 1.5 hours per day over a period of 24 weeks. After every four-week block, the speech therapist and the independent listener assessed the clarity of the same test cases. As in the pilot study, this assessment was done without using the Haptic Chair in order to make a fair comparison. In addition, the independent listener was not aware of which students were in the control and experimental groups. We used the same performance indicator as in the pilot study (number of clearly spoken words), except that the maximum possible score was now 20.

Results

Four participants (out of the 20) did not complete the entire study. One from the experimental group (after eight weeks) and three from the control group (two after eight weeks, one after 12 weeks) dropped out from the study. Their scores were included in the calculation of means during the period of their participation. As in the pilot study, all participants showed an increase in performance with time. Again, this is expected due to the familiarity they gain with the test word set as well as the teaching that is part of the therapy.

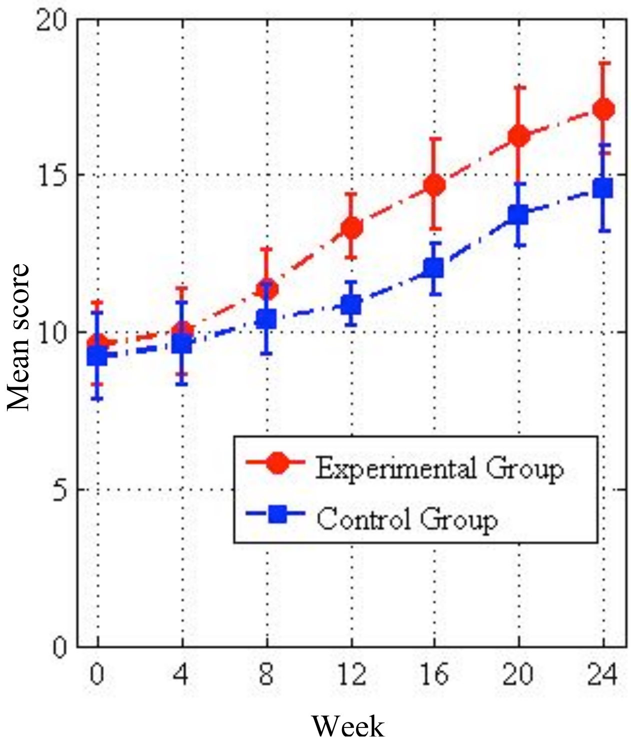

Figure 3: Follow-up study: Mean score (average number of words recognized by the speech therapist) after every 4-weeks with 95% confidence interval.

Figures 3 and 4 show the mean score for each of the groups assessed by the speech therapist and the independent listener respectively. Both the speech therapist's and the independent listener's assessments showed a similar trend. However, as might be expected, the independent listener's scores were lower than the speech therapist's scores. This might have been due to the fact that the speech therapist was more familiar with the individual students' pronunciations.

Based on the speech therapist's assessment (Figure 3), there was no significant difference in performance between the two groups during the first eight weeks. However, from week 12 onwards, the group who used the Haptic Chair performed significantly better than the control group. At the end of the 24th week, the experimental group's performance score was significantly higher, $t(14) = 2.55$, $p < 0.05$, than that of the control group.

From the independent listener's assessment (Figure 4), the two groups showed similar performance during the first 12 weeks. The experimental group performed significantly better from week 16 onwards. At the end of week 24, on average subjects in the group that used the Haptic Chair were able to pronounce 75% percent of the test words clearly. This score is significantly higher, $t(14) = 5.39$, $p < 0.001$, than the score of the group who went through the standard speech therapy program.

Qualitative Observations

The statistical analysis described in the previous section suggests that the Haptic Chair has the potential to be a useful tool in the context of speech therapy sessions for profoundly deaf children. To provide a qualitative analysis of the vibrotactile signal, a short speech sample was played through the Haptic Chair and the vibration pattern was recorded using an accelerometer (3041A4, Dytran Instruments, Inc.). When the recorded vibration pattern was played back as an audio signal, the resulting sound had the same quality as the original signal. This was a casual observation; however, it supports our assertion that the vibrations produced by the chair did not have any significant distortions.

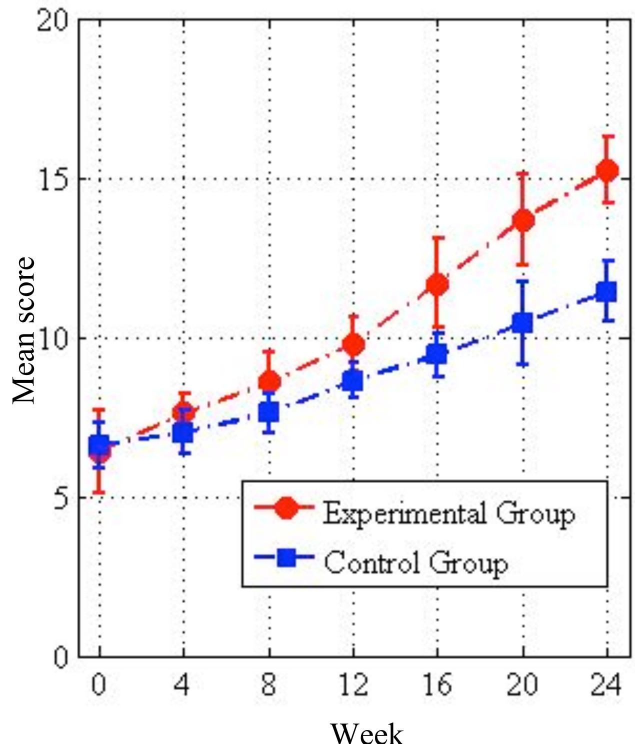

Figure 4: Follow-up study: Mean score (average number of words recognized by the independent listener) after every 4-week block with 95% confidence interval)

In addition, we asked the speech therapist and the independent listener to provide qualitative observations such as general speech ability, voice quality, omission of certain sounds and other general comments. These comments provided additional insight. The speech therapist reported that the Haptic Chair was intuitive to include and use in the speech therapy sessions. Both the speech therapist and the independent listener agreed that the participants who used the Haptic Chair were more enthusiastic about attending speech therapy sessions. One participant (P3 from the experimental group) made a comment, "*Yes, I can hear from my legs*", which we have heard in previous experiments on musical enjoyment. According to the speech therapist, many participants from both groups were able to combine words and pronounce sentences. However, at the end of the 24-week study period, the experimental group showed almost no word omissions whereas the participants from the control group still omitted some words in a sentence. (It is important to note that although there were no omissions, not all the words could be understood by the speech therapist.) Moreover, the speech therapist also observed a noticeable improvement of the quality of the voice of some participants in the experimental group.

We also observe that the deaf children often have a negative feeling about speaking because they think their voice may not sound like hearing people. They became less sensitive about this as they got used to feeling the speech therapist's speech and their own speech. We do acknowledge that our studies might have been confounded by a host of cultural differences between the Sri Lankan population we studied and others, or between different age groups but hope they will contribute to improvements in oral/audio communication for all parties concerned.

CONCLUSION AND FUTURE WORK

We conducted a 12-week long pilot study and a 24-week long follow-up study to evaluate the effectiveness of the Haptic Chair in speech therapy sessions for profoundly deaf students. Our results suggest that the additional vibrotactile feedback provided by the Haptic Chair had a positive impact on speech learning in this context.

The current system, makes no attempt to electronically process the speech in any way, but instead delivers the entire input audio stream to each of the separate vibration systems targeting the feet, back, arms and hands. This is not necessarily the optimal strategy for vibrotactile presentation (Karam et al., 2008, 2009). In future work, we will explore the possibility of providing customised (e.g. separated by frequency bands) vibrotactile feedback through different vibration elements to different locations on the body. Moreover, we are focusing on extending the Haptic Chair concept into a wearable or portable device. We hope that these future works will lead to more effective uses of the vibrotactile channel for communication *via* speech for the profoundly deaf.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the support of the following people at Dr. Reijntjes School for the Deaf, Sri Lanka: Mrs. Tineke De Silva (the principal), for her exceptional enthusiasm and continuous help without which this research project would not have been possible; Buddhini Gunasinghe (the speech therapist/sign language interpreter) for facilitating the interaction with deaf students and supporting the user studies; the teachers and supporting staff for their cooperation in successfully conducting the studies; and on top of all, the students for continuously taking part in this study and their parents for providing their consent.

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