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Effect of Computer-Assisted Speech Training on Speech Recognition and Subjective Benefits for Hearing Aid Users with Severe to Profound Prelingual Hearing Loss

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Abstract

Objective: Computer-assisted speech training is a speech recognition training system developed for cochlear implant users. With minimal facilities and skills, cochlear implant users can conduct this training at home. The purpose of this study was to apply this system to adolescent and young adult hearing aid users with prelingual severe to profound hearing loss.

Study sample: Fifteen Mandarin-speaking hearing aid users with prelingual severe to profound hearing loss were included into this study. Another 6 hearing aid users with a similar background were recruited as the control group.

Results: The training group had significant improvements in monosyllabic word recognition after 8 weeks of training, however the improvement diminished after 12 weeks of training. The training group also had significant improvements in consonant recognition after training for 12 weeks. There were no differences in improvement and final scores on the client-oriented scale of improvement between the training and control groups.

Conclusion: With moderate training, the computer-assisted speech training system showed some benefits in training hearing aid users with prelingual severe to profound hearing loss, especially in the recognition of monosyllabic words and consonants.

Keywords CAST; Hearing aids; Speech recognition; Cochlear implants

Introduction

Sensorineural hearing loss (SNHL) is a disability affecting people worldwide, and the prevalence is expected to increase due to prolonged life expectancy. SNHL has a significant negative impact on the quality of life, especially in prelingually deafened children. Except for certain diseases such as sudden deafness or endolymphatic hydrops, which may be treated or alleviated by medication or surgery, most patients with SNHL have to wear hearing aids or undergo cochlear implantation to regain hearing. However, for many individuals these measures do not satisfactorily resolve communication problems, because hearing is only the first step in a series of events leading to communication. Between hearing and communication lie the important skills of listening and comprehension, and to achieve successful communication it has been suggested that patients receiving amplification should be offered some type of audiological rehabilitation [1]. It has been reported that older subjects do not spontaneously acclimatize to wearing a hearing aid, or that the effects are either small or nonexistent, which emphasizes the importance of rehabilitation after wearing a hearing aid [2]. Unfortunately, not everyone with SNHL in Taiwan receives this kind of rehabilitation. The reasons for this may be: (a) methods of rehabilitation are not familiar to all clinicians or speech pathologists; (b) there is a shortage of clinicians or speech pathologists to provide such time-consuming rehabilitation; (c) hearing impaired patients may be unable to afford or are unwilling to dedicate time to rehabilitation; and (d) it is difficult to measure the improvements provided by rehabilitation.

Recently, rehabilitative training procedures have been garnering interest due to technological advances enabling a hearing aid user to perform the procedures while at home using a personal computer [3]. Burk et al. trained young normal-hearing and older hearing-impaired listeners with digitally recorded training materials using a computer. The results showed that older hearing-impaired listeners were able to significantly improve their word-recognition abilities through training with one talker, and to some degree achieve the same level as young normal-hearing listeners. In addition, the improved performance was maintained across talkers and across time.

The computer-aided speechreading training (CAST) system was developed to simulate a face-to-face training intervention and was designed to be one component of a comprehensive aural rehabilitation program for preretirement adults with acquired mild-to-moderate hearing loss [4]. The aim of the training was to enhance speechreading skills to complement auditory speech perception. Throughout the training, the learner views a monitor that shows either a computer-generated screen or a videotaped recording of the teacher. CAST was designed to be used by a clinician to extend rather than to replace existing rehabilitative techniques.

Computer-based training has also been applied to the rehabilitation of cochlear implant users. Before the development of computer-based training, some studies assessed the effects of limited training on the speech-recognition skills of poorer-performing cochlear implant users. Busby et al. [5] conducted ten 1 hour speech perception and production training sessions, and the results demonstrated minimal changes in perceptual abilities in three cochlear implant users. Dawson and Clark [6] conducted one 50-minute training session per week for 10 weeks, and four of five subjects showed some measure of improvement. The limited success of these attempts to improve the speech-recognition abilities of cochlear implant users was thought to be due to an inadequate amount of training [7]. More intensive training of cochlear implant users was predicted to be effective, because in normal hearing populations training has been shown to successfully improve speech segment discrimination and identification [8], and recognition on spectrally shifted speech [9]. Fu et al. [7,10] reported encouraging results in the rehabilitation of cochlear implant users using a computer-assisted speech training system which they also called CAST, although this was different to the CAST system of Pichora-Fuller and Benguerel. The CAST system of Fu et al. developed at the House Ear Institute, contains a large database of training materials and can be installed on personal computers, and so with minimal facilities and skills, cochlear implant users can conduct the training at home, and clinicians or speech pathologists can monitor the subject's test score and training progress. The results demonstrated that after moderate amounts of training (1 hour per day, 5 days per week), all 10 postlingually deafened adult cochlear implant users in the study had significant improvements in vowel and consonant-recognition scores. Wu et al. [11] applied the CAST system to 10 Mandarin-speaking children (three hearing aid users and seven cochlear implant users). After training for half an hour a day, 5 days a week, for a period of 10 weeks, the subjects showed significant improvements in vowel, consonant and Chinese tone performance. This improved performance was largely retained for 2 months after the training had been completed. Stacey and Summerfield [12] also used computer-based auditory training to improve the perception of noise. The results confirmed that the training helped to overcome the effects of spectral distortions in speech, and the training materials were most effective when several talkers were included.

Based on these previous studies, cochlear implant users can improve their speech recognition ability after training with a CAST system. If this system is also effective for hearing aid users, and especially prelingually deafened patients, the CAST system will have a substantially positive impact, as there are many more hearing aid users than cochlear implant users.

The purpose of this study was to train prelingually deafened adolescents and young adults with CAST and measure the benefits objectively and subjectively. The objective benefits were measured using published speech recognition tests [13], and the subjective benefits were measured using client-oriented scale of improvement (COSI) [14].

Materials and Methods

Subjects

Fifteen hearing aid users with prelingual severe to profound hearing loss participated in this study. Another six hearing aid users with a similar age and hearing average were included as the control group. The inclusion criteria for the study subjects and controls were: (1) age above 15 years; (2) wearing a hearing aid for at least for 2 years after hearing loss was diagnosed; (3) basic ability to operate a computer; (4) Mandarin Chinese speaker; and (5) motivation to undertake the training program. The exclusion criteria were: (1) aided hearing average worse than 70 dBHL; (2) unable to operate a computer. Before training with CAST, all participants received unaided and aided sound field audiometry. Table 1 shows the basic information of the 21 participants.

Training	**Age (years)**	**Gender**	**Unaided hearing average (dB)**	**Aided hearing average (dB)**
S1	15	M	105	33.33
S2	18	F	108.33	68.33
S3	24	M	113.33	65
S4	19	F	81.67	45
S5	19	M	101.67	60
S6	15	F	103.33	53.33
S7	21	F	106.67	53.33
S8	23	F	110	65
S9	24	M	106.67	50
S10	22	M	96.67	63.33
S11	21	M	96.67	60
S12	22	M	101.67	31.67
S13	16	M	93.33	31.67
S14	17	M	96.67	38.33
S15	17	M	96.67	45
Control	**Age (years)**	**Gender**	**Unaided hearing average (dB)**	**Aided hearing average (dB)**
S16	24	M	86.67	25
S17	30	F	98.33	51.67
S18	26	M	110	41.67
S19	27	F	95	48.33
S20	23	M	112.5	51.67
S21	16	M	101.5	33.33

Table 1: Basic information of the training and control groups.

Client-oriented scale of improvement (COSI)

We use a COSI questionnaire to evaluate subjective benefits [14]. Before training with the CAST system, both the training and control groups were asked to identify up five specific situations in which they would like to cope better. At the end of the training, for each situation they were asked (A) how much better (or worse) they could now hear, and (B) how well they were now able to cope. For scaling purposes, the responses were assigned scores from 1 to 5, with 5 corresponding to "much better" and "almost always", 4 corresponding to "better" and "most of the time", 3 corresponding to "slightly better" and "half the time", 2 corresponding to "no difference" and "occasionally", and 1 corresponding to "worse" and "hardly ever", for questions A and B, respectively. Question A was defined as an "improvement", and question B was defined as "final ability". The total scores of the five situations were compared between the training and control groups.

Test materials and procedures

The speech recognition test materials including monosyllabic words, disyllabic spondee words, vowels, consonants and Chinese tone recognition tests were recorded onto a CD-ROM at Melody Medical Instruments Corp. by a male and female speaker. The test materials were displayed on a laptop computer connected to a GSI 61TM clinical audiometer (Grason-Stadler, USA) at an output level of 70 dBHL. The testing procedure was performed in a double-walled, sound-treated room.

Monosyllabic Chinese word recognition test materials included four blocks of 25 Chinese words. For each speech recognition test, 50 words were selected resulting in a set of 50 tokens. After a monosyllabic Chinese word was displayed, the participants were asked to write down the word. Four different sets of open-set tests were generated for each speech recognition test. Disyllabic Chinese spondee-word recognition test materials included two blocks of Chinese spondee-words, each block containing 36 Chinese spondee-words. For each speech recognition test, one block was selected resulting in a set of 36 tokens. After a Chinese spondee-word was displayed, the participants were asked to write down the word. Four different sets of open-set test were generated via changing the order of the materials for each speech recognition test.

Vowel recognition test materials included 16 Chinese words. Vowel recognition was measured using a 4-alternative, forced-choice procedure in which Chinese characters were shown on the choice list. For each speech recognition test, the order of the words was changed. Thus, four different sets of closed-set tests were generated. Consonant recognition test materials included 21 Chinese words. Consonant recognition was measured using a 4-alternative, forced-choice procedure in which a Chinese character was shown on the choice list. For each speech recognition test, the order of the words was changed, and thus four different sets of closed-set tests were generated. Chinese tone recognition test materials [13] included 50 Mandarin Chinese words. The participants were asked to write down the Chinese tone (tone: 1: flat; 2: rising; 3: falling-rising; 4: falling) after the Chinese word was displayed. For each speech recognition test, the order of the words was changed, and thus four different sets of open-set tests were generated.

Before training, both groups underwent a series of speech recognition tests as baseline data. The training group then started training whereas the control group did not receive any training. Every 4 weeks, the participants returned to the lab for another series of speech recognition tests using different test materials. Every participant had received a total of four speech recognition tests by the end of the study.

Training tools and procedures

CAST software developed at the House Ear Institute and distributed by Melody Medical Instrument Corp. was used as the training tool. The training group was instructed to train at home following the program for at least 1 hour per day, 3 days a week, for 12 successive weeks. The control group did not receive any training and returned to the lab every 4 weeks for speech recognition tests. For each participant in the training group, a baseline speech recognition test was performed after the software had been installed into his or her personal computer. The results were analyzed by the software which then automatically generated a targeted training program. The software contained a large amount of information including pure tone, vowel recognition, consonant recognition, tone recognition, speaker recognition, environmental sounds, occasional words and occasional sentences. The subjects were asked to focus on pure tone, vowel recognition, consonant recognition and tone recognition training. The subjects started the training at a level generated by the computer software. There were usually five levels of difficulty in each training category, and each level consisted of several training sessions. For pure tone recognition training, the subjects were asked to choose the sound different to the others. Visual feedback was provided as to whether the response was correct or incorrect. After a training session had been completed, the score was calculated. If the score exceeded 80, the training proceeded to a higher level. If the score did not exceed 80, the training session was repeated until the score exceeded 80. At a higher level of training sessions, the differences between speech features in the response choices were reduced. For vowel recognition training, the subjects were asked to choose the vowel different to the others. After the subjects had progressed beyond the 3-alternative forced-choice discrimination task, they were trained to identify final vowels. Similar training procedures were used for consonant and tone recognition training.

Each subject in the training group was asked to register on the Melody Medical Instrument Corp. website, and his or her username and password were provided to us. Therefore, we were able to monitor the total time spent training, and the training time and score for each exercise. If the subjects did not reach the required amount of time and training sessions, we contacted their family and encouraged them to do more training.

Statistical methods

All statistical analyses were performed with SAS software (Version 9.1.3, SAS Institute Inc., Cary, NC, USA) and R software (Version 2.7). Two-sided p values of 0.05 or less were considered to be statistically significant. Continuous data were expressed as mean ± standard deviation (SD) unless otherwise specified. Percentages were calculated for categorical variables. Two-sample t tests or Wilcoxon rank-sum tests were used to compare the means or medians of continuous data between two groups, whereas the chi-squared test or Fisher's exact test was used to analyze categorical proportions between two groups.

In addition to univariate analyses, the data of the five speech recognition tests were analyzed by fitting multiple marginal linear regression models using generalized estimating equations. If the first-order autocorrelation (i.e., AR(1)) structure fit the repeated measures data well, the model-based standard error estimates were used in the generalized estimating equations analysis; otherwise, the empirical standard error estimates were reported. In addition, the data of COSI were analyzed by fitting multiple linear regression models.

Basic model-fitting techniques for variable selection, goodness-of-fit assessment, and regression diagnostics were used in our regression analyses to ensure the quality of the results. In stepwise variable selection, all of the univariate significant and non-significant covariates were considered, and both the significance levels for entry and for stay were set to 0.15 or larger. The goodness-of-fit measure, the coefficient of determination (R2), was computed for all of the linear regression models, which is the square of the correlation between the observed response variable and the predicted value. It had a value between 0 and 1, with a larger value indicating a better fit of the multiple linear regression model to the observed continuous data. In addition, the variance inflation factor was examined to detect potential multicollinearity problems (defined as a value ≥10).

Results

Twelve of the 15 subjects in the training group completed the 12 week training course, five speech recognition tests, and COSI, and the other three subjects dropped out due to poor compliance. All of the six participants in the control group completed the five speech recognition tests and COSI. Table 1 shows the basic information of all subjects. The group mean plots of the speech recognition tests were compared between the training and control groups (Figure 1). The multivariate analysis results of the five speech recognition tests are listed in Table 2.

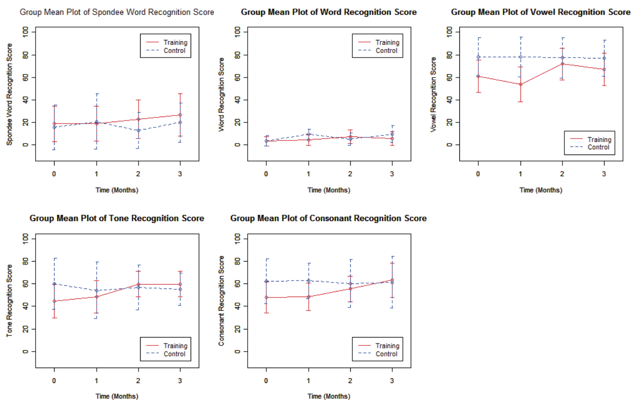

Figure 1: Group mean plot of speech recognition tests.

Covariate	Estimate	Standard Error2	95% Confidence Limits		Z	Pr>|Z|
Monosyllabic Word Recognition Test						
Word recognition pre-training	1.0993	0.0918	0.9193	1.2793	11.97	<0.0001
Control 8 weeks3	-4.13	1.1185	-6.322	-1.938	-3.69	0.0002
Training 8 weeks3	6.5287	1.3666	3.8502	9.2072	4.78	<0.0001
Disyllabic Spondee-word Recognition Test						
Spondee-word pre -training	0.9299	0.0562	0.8197	1.04	16.55	<0.0001
Vowel Recognition Test						
Vowel recognition pre-training	0.8275	0.1079	0.616	1.039	7.67	<0.0001
Training 4 weeks3	-12.02	3.0655	-18.03	-6.008	-3.92	<0.0001
Consonant Recognition Test						
Consonant-recognition Pre-training	0.6591	0.0977	0.4675	0.8506	6.74	<0.0001
Training 12 weeks3	7.8673	3.1977	1.5999	14.135	2.46	0.0139
Chinese Tone Recognition Test						
Hearing-average	-0.504	0.2303	-0.955	-0.053	-2.19	0.0287
Tone recognition pre-training	0.6228	0.0731	0.4794	0.7661	8.52	<0.0001

Table 2: Marginal linear regression analysis of five speech recognition performance over speech recognition tests every 4 weeks using the generalized estimating equations method[1]. [1]The repeated measures data were analyzed by multiple marginal regression models using the generalized estimating equations (GEE) method to assess the scores of five speech recognition tests after training with CAST. The statistically insignificant (P>0.05) training scores and other variables are not listed in the table. [2]The empirical standard error estimates of the GEE method are listed. [3]The term "training n weeks" refers to the scores of training group compared with pre-training score after training for n weeks. The term "control n weeks" refers to the scores of control group compared with pre-training score after n weeks.

Monosyllabic word recognition test

A significant improvement was found after 8 weeks of training with the CAST system (p<0.0001), however the significant improvement diminished after 12 weeks of training. The control group showed a significant deterioration in monosyllabic word recognition after 8 weeks (p=0.002), however the deterioration was not present after 12 weeks. In addition, the higher the pre-training score, the higher the final testing score (p<0.0001).

Disyllabic spondee-word recognition test

There was no significant improvement after training with the CAST system. The score of the control group showed no significant changes among the four disyllabic spondee-word recognition tests. The higher the pre-training score, the higher the final score (p<0.0001).

Vowel recognition test

There was a significant deterioration after 4 weeks of training with the CAST system (p<0.0001). However, no significant differences were noted after 8 and 12 weeks of training. The scores of the control group showed no significant changes among the four vowel recognition tests. Again, the higher the pre-training score, the higher the final score (p<0.0001).

Consonant recognition test

There was a significant improvement after 12 weeks of training with the CAST system (p=0.0139). The scores of the control group showed no significant changes among the four consonant recognition tests. Again, the higher the pre-training score, the higher the final score (p<0.0001).

Chinese tone recognition test

There was no significant improvement after training with the CAST system. The scores of the control group showed no significant changes among the four Chinese tone recognition tests. The higher the pre-training score, the higher the final score (p<0.0001).

Client-oriented scale of improvement (COSI)

The average improvement in the score of the training group was 12.67, and the average improvement in the score of the control group was 11. The average final ability score of the training group was 14.83, and the average improvement score of the control group was 14.83. There were no differences in improvement score and final ability after training with the CAST system. The control group also showed no difference after 12 weeks. Table 3 shows the COSI results.

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr>|t|
COSI Improvement					
Aided-hearing average	1	0.113	0.039	2.9	0.011
Male gender	1	3.4574	0.8951	3.86	0.0015
COSI Final Score					
Consonant recognition pre-training	1	0.116	0.0259	4.48	0.0004

Table 3: Multivariate analysis of COSI improvement score and final score between the training group and control group using multiple linear regression analysis[1]. [1]The statistically insignificant (P>0.05) scores and other variables are not listed in the table.

Discussion

The results from the present study demonstrated that consonant recognition scores improved after 12 weeks of training with the CAST system. The monosyllabic word recognition test score also improved after 8 weeks of training, although this improvement did not last to the end of the study. The scores of disyllabic spondee-word recognition, vowel recognition and Chinese tone recognition showed no significant improvement after training. Although it appeared as though the subjects in the training group did feel some improvement after training, the improvement scores of COSI failed to demonstrate statistical significance. While the results of previous studies for adult cochlear implant users [10] and child cochlear implant and hearing aid users [11] were encouraging, our study showed less impressive results.

Several possible reasons may contribute to the differences in our results from previous studies. Our study subjects may be the most challenging group of hearing impaired patients to receive training. The age of our participants ranged from 15 to 30 years, and they were all prelingually deafened. However, the study subjects in previous studies were postlingually deafened adult cochlear implant users [10] or prelingually deafened children [11]. It is believed that the children who receive cochlear implants at an earlier age with a short duration of deafness will benefit more from the implants than children with a longer duration of deafness [15]. The same concept may apply to hearing aid users. Therefore, training group subjects may experience greater benefits from training with the CAST system after more extensive training. Our training program consisted of 1 hour per day, 3 days per weeks, for 12 successive weeks, which is different from the previous studies. Although no standardized training program has been established, previous studies using protocols such as 1 hour per day, 5 days a week [7], and half an hour a day, 5 days a week, for 10 successive weeks [11] both demonstrated promising results. The subjects in the current study were mostly students who had a lot of homework, and it was therefore difficult to ask them to train for more than 5 hours a week with the CAST system. As mentioned previously, this group of hearing impaired patients is the most challenging to train, and a more intensive training program may have resulted in more significant improvements.

Although our participants were severe to profound prelingual hearing aid users who had the same hearing average as cochlear implant users, the functional gain from hearing aids may not be equal to that from cochlear implants. In the current study, six of the training group subjects still had a hearing average over 60 dBHL when they wore hearing aids. It is not surprising, therefore, that these subjects did not benefit from their hearing aids. As they apparently did not obtain much functional gain from their hearing aids, they may be candidates for cochlear implantation. If such subjects cannot really "hear" the training material, the training may not work. It is well known that hearing aids have little effect in gaining high frequency hearing, which is critical for consonant recognition. Cochlear implants can bypass the hair cells in the cochlea and directly stimulate auditory nerves. Thus, cochlear implant users usually have better performance at high frequencies than hearing aid users, except for hearing aids with frequency transposition technology. Interestingly, the only speech recognition test that had a significant improvement was the consonant recognition test. This can be explained due to the limited case number. As shown in Figure 1, the group mean plots of the speech recognition tests all demonstrated a trend of improvement after training. The COSI results also revealed a greater improvement in scores in the training group. If more cases had been enrolled in this study, it is possible that the other speech recognition tests may have shown statistical significance. In other studies related to speech training, Fu et al. [7] recruited 10 subjects, Wu et al. [11] recruited 10 subjects, Stacey et al. [12] recruited 16 subjects, Dawson et al. [6] recruited 5 subjects, Sand et al. [3] recruited 23 subjects (16 normal hearing young adults and 7 hearing impaired adults). It is generally difficult to find enough subjects for this kind of study that can meet statistical requirements.

There was initial gap in the tone and consonant discrimination between the control and trained groups. A possible reason is that although we selected age and hearing level matched control group, there were still several subjects within the trained group that had particularly bad hearing and bad initial testing score. Unfortunately we were not able to recruit initial testing score matched control group due to relatively small sample size. Ideally the control and study group should have similar discrimination at the beginning of the study to have better judgment for the training program. However, our statistical analysis compared the testing score for both groups every 4 weeks. In other words, we compared the score improvement in each group. We believe this can still evaluate the effectiveness of the CAST program.

Testing materials were not used in the software. Instead, we used speech recognition tests that have already been published in Taiwan [13]. The advantage is that we were able to evaluate whether or not the learned material could be used in daily communication, since the testing material was recorded by different people and different speeds in a more colloquial manner. However, there were also some flaws in these tests. First, the number of testing tokens was inadequate, especially in the vowel recognition test. There were only 16 tokens in each vowel recognition test, which will exaggerate the standard deviation. One subject (S9) had an obvious decline in all speech recognition test scores after training 4 weeks with CAST system, due to problems with his hearing aid. This may partially explain why there was a decline in vowel recognition after training for 4 weeks. Second, due to large inter-subject variation, the speech recognition tests were not suitable for all of the participants. For example, one may have scored zero in four open-set monosyllabic Chinese word recognition tests, while another may have scored 100 in four closed-set vowel recognition tests.

Finally, compliance is still a concern. Although all of the training group subjects had the motivation to undertake our program, too many external factors including school work made it difficult for them to concentrate on the training program. Thus, even though we monitored their pace of training, it was difficult to keep an eye on every subject. In addition, due to large inter-subject variation, the amount of training within an hour differed from subject to subject. Therefore, in addition to personal motivation, the subjects should also have strong family support if they are going to undertake speech recognition training with a CAST system.

Conclusion

The results showed that training with a CAST system provided some benefits in hearing aid users with prelingual severe to profound hearing loss. However, the effects were not significant compared with previous studies. Thus when applying CAST to such hearing aid users, careful assessment of the functional gain of the hearing aid and ensuring good compliance should be mandatory.

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