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Preliminary evaluation of the speech perception assessment and training system (SPATS) with hearing-aid and cochlear-implant users

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I. INTRODUCTION

Numerous recent studies have demonstrated improved speech perception by hearing-impaired listeners after training (Burk et al., 2006; Burk and Humes, 2007; Burk and Humes, 2008; Fu, 2007; Miller et al., 2004; Miller et al., 2005; Stecker et al., 2006; Sweetow and Henderson-Sabes, 2004; Sweetow and Palmer, 2006; Sweetow and Sabes, 2006). This study was conducted as a preliminary evaluation of the usefulness of the Speech Perception Assessment and Training System (SPATS, patent pending) with hearing-aid and cochlear-implant users. The methods and results are described. Additional details of the SPATS program are given by Miller et al., 2007.

II. METHODS AND PROCEDURES

A. Participants

Twelve hearing-aid users and 16 cochlear implant users served as paid participants in this study. The hearing-aid users were recruited in Bloomington, IN and they are described in Table 1. The cochlear-implant users were recruited at the Heuser Hearing Institute in Louisville, KY and are described in Table 2. These samples include a wide range of ages, types of hearing-loss, and histories.

B. Pre- and Post-Tests

The participants were pre-tested on a variety of non-SPATS tests and then on a variety of SPATS tests. After pre-testing the controls were given a several week hiatus, while the trained participants were scheduled for 6 weeks of training (two two-hour sessions each week). Finally, all participants were post-tested on SPATS tests and then on non-SPATS tests. Table 3 lists the non-SPATS tests used for the HA-users and the CI-users. These were administered both before and after training for the trained participants and before and after a several week hiatus for the control participants. All speech materials were presented at 65 dB SPL.

The SPATS tests are listed in Table 4. The first row gives the combinations of constituent types and levels. For each combination, one test was run in the quiet and the other was adaptive in noise. Adaptive testing and training in noise (12-talker babble) was done using Kaernbach's weighted up-down procedure (Kaernbach, 1991) to find the SNR for a target percent correct (TPC). The target percent correct (TPC) was chosen as 10% below the listener's score in quiet. (This rule has been abandoned in current versions of SPATS as it is clinically inappropriate to ask clients to adapt to target scores below 50% correct.) Sentence testing was done with the Sentence Module (patent pending). One test was done with no sound to test the individuals' abilities to guess the words in sentences. A second sentence test was done auditorily but with the SNR adapted in accordance with the subjects' performance. These procedures are described in more detail in the companion paper Miller et al., 2007. Nuclei Level 1 consists of the 7 most important vowels of English. Nuclei Level 3 has the 21 most important vowel and vowel-like sounds of English. Onsets Level 1 consists of the 11 most important beginnings of English words, while Onsets Level 3 consists of the 34 most important beginnings of English words. ("Importance" was scaled in terms of frequencies of occurrence, see companion paper for details.) In a test each item in the set is presented 4 times, with talker and vowel chosen randomly. For onsets each item in a set was recorded by 8 talkers as combined with each of four vowels (/i/, /a/, /u/, /ə/). The vowels were also recorded by 8 talkers but in only one context, hVd.

C. Training

Training was organized as a "training rotation." The goal was to complete 12 rotations, where each rotation included training on the identification of syllable onsets and nuclei in quiet and in noise and training in identifying short sentences at signal-to-babble ratios that were adapted to each participant's performance. A training rotation is summarized in Table 5.

There are several characteristics of the training rotation worthy of comment. For syllable constituents, training runs used the adaptive item selection (AIS) algorithm (patent pending) described in the companion paper. AIS is designed to focus training on learnable items of intermediate difficulty. Levels 1 and 3 were selected for constituent training so that the participants would alternate between easier and more difficult tasks as means of maintaining motivation. The sentence task was intermixed with the constituent tasks. Sentence scores calculated after each group of three sentences were used to adjust the SNR for the next set of three sentences. With breaks included most participants were able to complete one rotation in a two-hour session. Three of the trained HA users completed six rotations or about 12 hours of training, as other obligations prevented them from completing all 12 rotations. All other trained HA and CI participants completed the 12 planned rotations for approximately 24 hours of training.

III. RESULTS

A. SPATS Tests

1. Hearing-Aid Users--Constituents in Quiet—The gains made at Levels 1 & 3 for onsets and nuclei varied from one individual to the next. Therefore, scores are presented for individual participants averaged across level (1 and 3) and constituent type (nuclei and onsets). The scores for individual HA users are presented in Figure 1 below; the upper panels show the results for testing in quiet. For each participant the average score on the pretests is shown by the red bar, the average score on the posttests by the black bar, and the gain by the green bar. The average gain for trained participants was about 8%, while that for controls was 0%. Note the individual differences.

2. Hearing-Aid Users--SNR Adaption—The bottom panels of Figure 1 show the participants' performance in noise in terms of % of Norm (%Norm). For every target percent correct and constituent type and level the signal-to-noise ratio obtained by normal-hearing listeners (SNR_N) was determined. A client's signal-to-noise ratio (SNR_C) was measured. The %Norm for an individual was calculated by Eq. 1.

$$\%Norm = ((SNR_C - 40) / (SNR_N - 40)) * 100, \quad (Eq. 1)$$

where the constant 40 represents effective quiet. If a client requires an SNR of 40 to achieve their target percent correct, they are unable to hear down into noise and their %Norm is zero. If the Client's SNR_C equals the SNR_N , their %Norm is 100. While there is individual variation, the average %Norm on pretest was 60%, while after training this number increased to 75% for a gain of 15%. The controls averaged about 73% on the pretest and fell to about 71% on the posttest for a rounded loss of 1%. These changes in %Norm for the trained group correspond to an average reduction in the SNR required to reach the target percent correct of 7.3 dB.

3. Cochlear-Implant Users—Constituents in Quiet & SNR Adaption—Figure 2 shows the results of constituent tests for the cochlear-implant users. In the upper-left panel it can be seen that two of the trained CI users showed substantial gains in percent correct in the Quiet, while the others did not. The mean improvement for the trained implant users was 6%, while for controls it was 0%. The improvements in noise were more consistent, with only one participant¹ showing no improvement. Indeed, the average improvement for the trained group in %Norm was almost 14%, while for controls it was 2%. These changes in %Norm for the trained group correspond to an average reduction in the SNR required to reach the target percent correct of 8 dB. Note the changes in %Norm for Participant 610. For those conditions where 610's target percent corrects (TPCs) were reasonable percentages, e.g. near 50%, this subject showed in gains in %Norm of about 20%. When the TPCs were very low, e.g. about 15%, this subject showed gains in %Norm of about -25%. In retrospect, it was unreasonable to ask the subject to track at such very low percentages.

4. Average Results for HA- and CI-users—The average results on SPATS constituent tests for HA- and CI-users are shown in Table 6. It is very clear that there were no gains for the controls and that trained participants improved by an average of 7% in quiet and 15% in terms of %Norm in noise. If one averages these scores, the overall average gain was 11% for the trained group and 0% for the controls, the former being a highly significant improvement. The t-values for the paired pre- and post-test measures were 10.0894 for the trained group ($df = 15$) and 0.3233 for the control group ($df = 11$), while the corresponding critical t-values ($\alpha = 0.05$ for two-tailed tests) were 2.1314 and 2.2010, respectively. The correlations between pre- and post-tests were 0.90 for the trained group and 0.96 for the control groups, indicating that the scores are reliable and that training does not substantially change performance rankings within a group.

5. Performance on the SPATS sentence tasks—In the course of training, the average participant, HA- or CI-user, listened to and successfully identified 367 sentences which combined to total 2040 words. About 24% of the total training time was spent working on the

¹The results for participant #610 illustrate the effects of asking a client to track to very low TPCs. As shown in the bottom left-hand panel of Figure 2, the average gain for 610 was negative and small. For two of the four conditions (Onsets and Nuclei at Level 1) his TPCs were near 50% and for these conditions he showed gains in %Norm with training of about 20%. For the other two conditions (Onsets and Nuclei at Level 3), his TPCs were near 15% and his gains were about -25%. Generally, it has been observed that tracking to very low TPCs was both confusing and discouraging to the participant.

sentence task. Almost all HA-users showed improvements in understanding the sentence material at signal-to-noise ratios of -5 to -15 dB. At this time, similar analyses have not been completed for CI users. No sentence data are shown for either group as we are in the process of revising the sentence task and developing appropriate measures that will allow comparisons to the performances of normally hearing peers. Nonetheless, it is believed that the sentence task is a necessary and key component of SPATS as it trains almost all of the relevant bottom-up and linguistic top-down skills involved in speech perception. All but one or two of the participants reported enjoying the sentence task and found it relevant to everyday hearing of speech. There were fairly large individual differences in their abilities to use context in this task.

B. Non-SPATS Tests

1. Hearing-Aid Users—The results for the hearing-aid users on non-SPATS tests are shown in Table 7. The last row of the table shows the mean difference between the trained and the control groups. Averaged over all measures the trained subjects improve by 8 percentage points more than the controls. However, for most of the participants the HINT scores were too high to allow significant improvement. Also, the CST-A-Only task was too difficult at the selected SNR. When the HINT and CST-A-Only scores are ignored, the trained subjects improved from pre- to post-tests by about 10 percentage points more than the controls. Overall, the improvements on non-SPATS measures were about equal to the improvements on SPATS measures.

2. Cochlear-Implant Users—The results for cochlear-implant users on non-SPATS tests are shown in Table 8. The last row of the table shows the mean differences between the trained and control groups. Training seemed to produce the greatest gains for HINT sentences in quiet. Overall the trained group improved 13% relative to the control group.

3. Non-SPATS Summary—If the results for all tests and both HA- and CI-users are averaged, it is found that the trained participants had a pretest average of 51% and a posttest average of 60% for a gain of 9%. The control participants had a pretest average of 52% and a posttest average of 51% for a loss of 1%. Overall the trained participants improved 10% relative to the controls. The t -values for the paired pre- and post-test measures were 5.9433 for the trained group ($df=15$) and 0.8452 for the control group ($df=11$), while the corresponding critical t -values ($\alpha=0.05$ for two-tailed tests) were 2.1314 and 2.2010, respectively. The correlations between pre- and post-tests were 0.88 for the trained group and 0.92 for the control groups, indicating that tests are reliable and that training does not substantially change score rankings within a group.

IV. SUMMARY AND CONCLUSIONS

Experienced hearing-aid and cochlear-implant users demonstrate improvements in speech perception after 12 to 24 hours of training on the SPATS system. This improvement is demonstrated by SPATS measures and by clinical audiologic tests in quiet and in noise. Participants ranged in age from 26 to 90 years. All participants, including the CI users, were capable of maneuvering through the SPATS program in a fairly independent manner. A wide range of hearing losses and hearing loss histories were included. The adaptive nature of the program allowed all participants to achieve enough correct identifications during training in order to keep motivation levels high. Overall, the trained participants showed gains of 11% over the controls. The controls showed no improvement. HA users commented that the program helped them to understand their hearing losses. They said that they became aware of their specific problems in the identification of speech sounds, and that they learned to attend to the details of sounds and to talker differences.

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FIGURE 1.

Results for HA-users on SPATS pre- and post-tests. Left panels are for trained participants and the right for control participants. The results are averages of the data for 4 conditions: Nuclei L1 & L3 and Onsets L1 & L3.

FIGURE 2.

Results for CI-users on SPATS pre- and post-tests. Left panels are for trained participants and the right for control participants. The results are averages of the results for 4 conditions: nuclei 11 & 12 and onsets 11 & 12.

TABLE 1

Hearing-aid users.

Number	Group	Age	SRT (best ear)	Speech (best ear)	Audiogram (best ear)	Hearing Loss
520	Trained	26	60 dB	96% at 90 dB	Flat	Sensorineural
517	Trained	71	47	not avail.	Sloping	Sensorineural
519	Trained	76	30	80% at 70 dB	High Tone	Sensorineural
511	Trained	79	30	80% at 70 dB	High Tone	Sensorineural
503	Trained	87	0	80% at 80 dB	Sloping	Sensorineural
504	Trained	87	20	84% at 69 dB	Steep Slope	Sensorineural
516	Trained	88	45	68% at 85 dB	Sloping	Sensorineural
513	Trained	90	85	72% at 100 dB	Flat at 65 dB	Mixed at Lows
514	Control	69	25	94% at 65 dB	Gentle Slope	Sensorineural
506	Control	70	15	96% at 55 dB	Mild High Tone	Sensorineural
502	Control	86	30	76% at 70 dB	Flat/Slope	Sensorineural
505	Control	86	55	88% at 95 dB	Gentle Slope	Sensorineural

TABLE 2

Cochlear-implant users.

Number	Group	Age	Onset Age	Years w/CI	Processor
620	Trained	35	26	1	Freedom
619	Trained	39	37	2	Freedom
504	Trained	42	3.5	4	Freedom
616	Trained	57	1.5	1	Freedom
610	Trained	69	64	5	Freedom
611	Trained	70	55	1	Freedom
613	Trained	70	41	2	Freedom
624	Trained	81	45	4	Sprint
617	Control	42	Early Childhood	4	3G
622	Control	42	Early Childhood	5	Freedom
623	Control	43	3	2	Freedom
625	Control	43	3 mos.	3	Freedom
628	Control	49	20	1	Freedom
627	Control	63	6R, 40L	3	Freedom
618	Control	64	44	6	Sprint
626	Control	79	59	19	3G

TABLE 3
The non-SPATS tests given to HA- & CI-users are listed.

HA	Test	W22	W22	HINT	HINT	CST-AV*	CST-A*
Users	SNR	(Quiet)	+ 8 dB	(Quiet)	+ 8 dB	-4 dB	- 4 dB
CI	Test	CNC		HINT	HINT		
Users	SNR	(Quiet)		(Quiet)	+10 dB		

* AV = Auditory-Visual, A = Auditory-Alone

TABLE 4

List of SPATS Tests given to HA- and CI- users.

Nuclei Level 1	Nuclei Level 3	Onsets Level 1	Onsets Level 3	Sentences
Quiet Adapt. to TPC [*]	Quiet Adapt. to TPC	Quiet Adapt. to TPC	Quiet Adapt. to TPC	No Sound Adaptive

^{*} TPC is target percent correct

TABLE 5

One rotation of training is shown.

Sequence	Constituents	Level	SNR	# Items	#Trials	Est. Time Minutes	Cum. Time Minutes
1	Nuclei	1	Quiet (+40 SNR)	7	28	3	3
2	Nuclei	1	SNR-Adapt. To TPC	7	28	3	6
3	Sentences	n/a	SNR-Adaptive	3 sets of 3 sent.		9	15
4	Nuclei	3	Quiet (+40 SNR)	21	84	10	25
5	Nuclei	3	SNR-Adapt. To TPC	21	84	10	35
6	Sentences	n/a	SNR-Adaptive	3 sets of 3 sent.		9	44
7	Onsets	1	Quiet (+40 SNR)	11	44	5	49
8	Onsets	1	SNR-Adapt. To TPC	11	44	5	54
9	Sentences	n/a	SNR-Adaptive	3 sets of 3 sent.		9	63
10	Onsets	3	Quiet (+40 SNR)	34	136	20	83
11	Onsets	3	SNR-Adapt. To TPC	34	136	20	103 (1 hr 43 m)

Table 6
SPATS constituent measures combined for HA- and CI-users.

Group	Quiet Percent Correct			SNR-Adaption % Norm			Mean		
	Pre	Post	Gain	Pre	Post	Gain	Pre	Post	Gain
Trained	55	62	7	57	71	15	56	67	11
Control	59	59	0	66	67	0	63	63	0

Table 7

Non-SPATS measures for hearing-aid users. All scores are in percent correct.

Tests			W22			W22			HINT			HINT			CST-AV			CST-A-Only			Mean	
Group	Participants	Quiet			+8 dB SNR			Quiet			+8 dB SNR			-4 dB SNR			-4 dB SNR			Non-SPATS		
		Pre	Post	Gain	Pre	Post	Gain	Pre	Post	Gain	Pre	Post	Gain	Pre	Post	Gain	Pre	Post	Gain	Post		
Trained	503	50	64	14	6	44	38	87	100	13	79	89	10	32	38	6	2	4	2	43	57	14
Trained	516	66	66	0	8	32	24	93	99	6	99	98	-1	13	20	7	4	3	-1	47	53	6
Trained	517	66	82	16	20	74	54	98	97	-1	92	92	0	6	5	-1	0	0	0	47	58	11
Trained	519	60	70	10	62	48	-14	85	91	6	75	80	5	12	22	10	2	1	-1	49	52	3
Trained	520	72	86	14	46	72	26	94	98	4	100	95	-5	42	55	13	8	14	6	60	70	10
Trained	504	70	84	14	26	62	36	100	99	-1	99	100	1	38	48	10	15	21	6	58	69	11
Trained	511	60	58	-2	28	64	36	99	100	1	97	97	0	61	68	7	23	22	-1	61	68	7
Trained	513	24	56	32	1	24	23	89	100	11	91	88	-3	13	24	11	4	5	1	37	50	13
Trained	Mean	59	71	12	25	53	28	93	98	5	92	92	1	27	35	8	7	9	2	50	60	9
Control	502	56	70	14	14	34	20	99	100	1	98	99	1	55	50	-5	5	4	-1	55	60	5
Control	505	60	58	-2	8	36	28	96	97	1	89	92	3	27	33	6	4	3	-1	47	53	6
Control	506	94	98	4	78	80	2	100	99	-1	99	99	0	83	60	-23	36	9	-27	82	74	-8
Control	514	88	96	8	76	88	12	100	100	0	100	100	0	39	39	0	17	6	-11	70	72	2
Control	Mean	75	81	6	44	60	16	99	99	0	97	98	1	51	46	-6	16	6	-10	63	65	1
T-C	Mean	-16	-10	6	-19	-7	12	-6	-1	5	-5	-5	0	-24	-11	13	-8	3	12	-13	-5	8

Table 8
Non-SPATS measures for cochlear-implant users. All scores are percent correct.

Tests		CNC			HINT			HINT			Mean		
Group	Participants	Pre	Post	Quiet	Gain	Pre	Post	Quiet	Gain	Pre	Post	Gain	Gain
+10 dB SNR													
Trained	504	84	88	4	98	100	2	57	78	21	80	89	9
Trained	610	44	50	6	60	85	25	41	59	18	48	65	17
Trained	611	24	26	2	71	62	-9	30	42	12	42	43	1
Trained	613	64	66	2	76	73	-3	25	27	2	55	55	0
Trained	616	20	34	14	21	63	42	19	19	0	20	38	18
Trained	619	48	62	14	78	98	20	60	69	9	62	76	14
Trained	620	44	50	6	62	83	21	35	61	26	47	65	18
Trained	624	48	44	-4	81	87	6	57	48	-9	62	60	-2
Trained	Mean	47	53	6	68	81	13	41	50	10	52	61	9
Control	617	62	48	-14	92	77	-15	63	32	-31	72	52	-20
Control	618	28	30	2	55	53	-2	15	23	8	33	35	2
Control	622	40	46	6	66	54	-12	35	31	-4	47	44	-3
Control	623	28	32	4	25	28	3	20	7	-13	24	22	-2
Control	625	70	66	-4	92	93	1	69	79	10	77	80	3
Control	626	60	48	-12	84	67	-17	47	62	15	64	59	-5
Control	627	70	66	-4	92	93	1	69	79	10	77	79	2
Control	628	60	48	-12	85	67	-18	47	62	15	64	59	-5
Control	Mean	52	48	-4	74	67	-7	46	47	1	57	54	-3
T-C	Mean	-5	5	10	-6	15	20	-5	4	9	-5	8	13