HEARING AID EVALUATION USING SPEECH PATTERN AUDIOMETRY

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ABSTRACT

A new PC-based speech perception testing system, the Speech Pattern Audiometer (SPA) is described which aims to provide a simple and efficient clinical tool to assess listeners' ability to make use of acoustic cues to speech pattern contrasts for use in speech and language therapy clinics with those who are deaf or who have developmental or acquired speech perceptual disorders. This system constitutes a module of a complete speech and hearing workstation.

INTRODUCTION

In order to plan stage-appropriate speech and language therapy and to ensure the best possible hearing aid fitting, it is important to be able to reliably measure a deaf person's ability to make use of speech pattern information in the acoustic signal. In making such an evaluation, the contribution of other sources of information such as contextual information at the lexical, syntactic and semantic levels needs to be minimised, or at least carefully controlled. This makes sentence and word lists quite unsuitable for an evaluation of acoustic cue use.

DESCRIPTION OF THE SPA

In speech pattern audiometry, the ability to make use of acoustic cues to phonemic contrasts is assessed using a set of identification tests. Each test is based on a minimal pair composed of words of high-frequency of occurrence and easily represented by a picture. Each test assesses the ability to perceive a specific set of acoustic cues such as those which mark intonation contrasts, vowel quality, and voicing, place and manner of articulation in consonants. High-quality copy-syntheses based on tokens produced by a female British English speaker are prepared and the speech pattern cues under investigation are manipulated in a controlled way to construct a set of stimulus continua. Unlike tests based on natural speech, the speech pattern elements in the copy-synthesised words can be individually manipulated whilst maintaining a high degree of naturalness. By comparing performance in different test conditions in which the speech pattern cues are presented singly or in combination, it is possible to make a precise assessment of the speech pattern information used by a listener. As the tests assess the perception of common components of speech sounds, conclusions can be drawn about other speech sounds that are distinguished by the same speech pattern elements without explicitly having to test them.

Phonemic contrasts differ in terms of their speech pattern complexity and this is reflected in the age and stage of development at which they are acquired. By choosing a set of contrasts that spans these different levels of speech pattern complexity, it is possible to assess for example the stage of speech development reached by a child.

The stimuli from the continuum are presented to the listener in the form of a two-alternative forced-choice identification test: the listener hears a word and responds by touching the appropriate picture on a touch-sensitive response box. The ability to assign the sound to a specific phonemic category, which is assessed in this test, is central to the whole process of speech perception. The output of the test is a simple graph called an identification or labelling function, which shows the percentage of responses of one label against the stimulus continuum. This graph can be economically described in terms of its gradient and phoneme boundary point, which are calculated using Maximum Likelihood Estimate (MLE) techniques [1]. Increasing confidence in identifying a contrast is marked by a sharpening of the identification function, and therefore by an increase in the measured gradient. These measures can be used in further statistical analyses, to look at evidence of change in performance over time or across different conditions.

The tests are *interactive* and the software which controls the test procedure determines the duration and complexity of each test on the basis of the client's ongoing performance. This is highly time- and cost-effective for the clinician, increases statistical reliability and ensures that clients are not frustrated by lengthy tests going beyond their ability. As each test takes only 3 to 4 minutes on average, it is possible to get a quantitative assessment of the perception of a range of contrasts within a twenty-minute session. Speech pattern audiometry has been evaluated in longitudinal studies of speech perception development with deaf children [2].

Test software and hardware

The SPA software has been implemented in Microsoft Windows. It includes facilities to store client records, to select and present minimal pair tests, to run interactive tests, to display and store test results in numerical and graphical form and obtain hard-copy printouts of the data. Facilities are also included to run basic statistics on the data.

The hardware required is a PC capable of running Microsoft Windows 3.1, fitted with a PCLX D/A card and a simple response box. In the absence of a response box, tests can be run using a mouse or joystick. As tests are usually carried out free-field aided, in a sound-treated room, a good quality amplifier and loudspeaker are also required. The sound level from the loudspeaker should be at the client's most comfortable listening level and must be monitored in each test session.

FIELD TRIALS

The sensitivity of both SPA and other audiometric tests for a particular evaluation of hearing aid performance was assessed in a study in collaboration with the Royal National Throat, Nose and Ear Hospital in London.

The test battery included the speech pattern tests described above and natural-speech based tests which take a similar analytic approach in assessing the use of acoustic information: the UCL 24-consonant VCV test [3] and the FAAF test [4].

Subjects

Subjects were four severely deaf listeners. All were regular hearing-aid users. They participated in the trial when they attended the clinic for their check-up approximately three months after being fitting with a new hearing aid.

Test battery

The listeners were each tested on a single day in two sound-proof rooms at the clinic. They were tested: (1) with their old aid; (2) with their new aid. In each condition, the following tests were presented in a "sound alone" condition (i.e. without lipreading).

Speech pattern tests

It was anticipated that for the clients selected, differences between hearing aids were most likely to be found in the perception of sounds cued by high-frequency patterns. Therefore 4 minimal pairs were selected which assessed the perception of place of articulation in initial plosives and fricatives. A initial-fricative voicing contrast was also included to assess the use of duration and low-frequency cues. The tests chosen were as follows (acoustic cues in parentheses).

- PEA-KEY (low-mid frequency burst and F2/F3 transitions)

- TEA-KEY (high-mid frequency burst and F2/F3 transitions)
- SUE-SHOE (mid-high frequency friction)
- SUE-ZOO (friction duration and presence/absence of voice bar)

24 consonant VCV test

The VCV test [3] investigates the perception of intervocalic consonants in nonsense words. An extended set of 24 consonants in a /a-a/ vowel environment was used. Each VCV was presented twice in random order. Listeners responded by writing a consonant on the answer sheet provided.

FAAF test

In the FAAF test [4] a test word is presented in a carrier sentence. The listener has to choose a response from four possible responses involving changes in the initial or final consonant contrast (e.g. "mail", "bail", "nail", "dale"). Each test contains 4 repetitions of 20 sets of stimuli. Results can be analysed to highlight the scores in voicing, place and manner of articulation.

Results

Speech pattern tests

Table 1: Identification function gradient for plosive contrasts.

	PEA - KEY		KEY - TEA	
Client	Old	New	Old	New
P001	-3.13	-1.87	*-1.31	0
P002	-5.00	-7.60	0	0.11
P003	-2.56	-3.51	*-0.28	0
P004	-1.07	-1.45	-0.39	-0.19

Table 2: Identification function gradient for fricative place and voicing contrasts.

	SHOE-SUE		SUE-ZOO	
Client	Old	New	Old	New
P001	-0.55	*-0.94	-1.12	-1.89
P002	-0.42	-0.44	-0.38	-0.24
P003	-0.93	-0.87	-3.51	-4.68
P004	-0.50	-0.34	-1.87	-1.56

The identification function gradients for each test with the two hearing aids are given above. The difference in gradient was judged as significant (marked by asterisk in Tables 1 and 2) if the gradients were a standard error apart.

For all listeners, steeper categorisation was obtained for contrasts marked by low-to-mid frequency cues (PEY-KEY and SUE-ZOO) than for mid-to-high frequency cued contrasts (SUE-SHOE and TEA-KEY).

Natural speech audiometry tests:

The difference in overall percent correct scores and in manner, voicing, and place of articulation scores obtained with the new versus old aid conditions for the two types of tests is presented in Tables 3 and 4.

Table 3: VCV test: Difference in scores between the new vs old aid.

	% total	% place	% voicing	% manner
P001	+18.7	+16.6	0	+10.0
P002	+38.8	+33.5	+33.5	+41.2
P003	- 4.2	+ 4.2	0	- 4.2
P004	0	- 4.2	+ 4.2	0.0

Table 4: FAAF test: difference in scores with the new vs old aid.

	% total	% place	% voicing	% manner
P001	+ 9	+ 4	+ 6	+ 3
P002	+ 3	+ 1	+ 3	- 5
P003	+ 5	+ 3	- 3	+ 3
P004	- 8	- 9	+ 3	- 3

Data analysis

P001 has six-frequency average (0.125 to 8 kHz) pure tone thresholds of 68 dBHL in the left ear and 38 dBHL in the right, with a flat configuration. She is labelling the PEA-KEY contrast sharply with both aids, but is showing better performance on the TEA-KEY contrast with the new aid, which suggests that this aid provides better frequency response at high frequencies.

Sharper labelling of the fricative contrasts is also seen with the new aid. Finally, P001 shows better performance with the new aid in both natural speech tests.

P002 labels the PEA-KEY contrast, marked by low-to-mid frequency cues, very confidently with both aids, but shows poor performance with both aids on the TEA-KEY contrast and the two fricative contrasts. These results correlate with a lack of significant increase in performance with the new aid in the FAAF test. A significant increase in performance with the new aid is seen for the VCV test, but a careful examination of results suggests that this is due to particularly poor results with the old aid due to fatigue.

P003 has 6FA pure tone thresholds of 47 dBHL in the left ear and 50 dBHL in the right, with a very steep configuration (15dB loss at 1 kHz and 95 dB loss at 8 kHz). As might be expected, sharp categorisation was seen for the two low-to-mid frequency cued contrasts, PEA-KEY and SUE-ZOO. Poorer performance is seen for the mid-to-high frequency cued contrasts but significantly sharper labelling for the KEY-TEA contrast was obtained with the old aid. The natural speech tests do not conclusively show better performance with either aid.

P004 had 6FA pure tone thresholds of 109 dBHL in the left ear and 88 dBHL in the right ear. He too obtained steeper identification functions for the low-to-mid frequency cued tests. There was a trend to label sharply with the old aid for 3 of the tests. He also obtained higher scores on the FAAF test with the old aid.

DISCUSSION

A new clinical tool for speech perceptual assessment, the SPA, has been presented which is based on extensively tested techniques used in experimental phonetics research.

A clinical example is presented in which SPA was compared to other speech audiometry tests to assess the relative efficacy of two hearing aids for deaf clients.

The VCV and FAAF tests evaluate the perception of a wide range of sounds. However, the VCV and FAAF feature-based performance measures (e.g. voicing and place correct) are still too general to provide much useful information for hearing aid fitting.

The speech pattern tests were successful in showing differences in performance which reflect the hearing aids' performance for low-frequency and high-frequency-based speech patterns. SPA had the further advantage of being quick and easy to administer, largely independent of vocabulary knowledge, and providing immediate scoring of results. This allows immediate feedback to be given to the client and results to be used within the session to make adjustments to hearing aid settings and try out new directions in rehabilitation. These tests therefore provide a valuable and powerful additional tool for audiological assessment.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the contributions of Belinda Walker, Zoe Attard and Dr Barbara Cadge and colleagues at the RNTNE. The SPA development was funded by a DTI SMART award to Laryngograph Ltd. The clinical study was funded by a grant from the Nuffield Foundation (NUF-URB94).

REFERENCES

[1] Bock, K.D. & Jones, L.V. (1968), *The measurement and prediction of judgment and choice*, San Francisco: Holden Day.

[2] Hazan, V., Fourcin, A.J. & Abberton, E. (1991) Development of phonetic labeling in hearing-impaired children. *Ear and Hearing*, vol. 12, pp. 71-84.

[3] Rosen, S., Moore, B.C.J. & Fourcin, A.J. (1979) Lipreading with fundamental frequency information. *Proceedings of the Institute of Acoustics*, IA2, 5-8.

[4] Foster, J.R., & Haggard, M.P. (1979) (FAAF) An efficient analytical test of speech perception. *Proceedings of the Institute of Acoustics*, IA3, 9-12.