Chapter 3

The Use of Speech-Perception Tests in Audiological Rehabilitation: Current and Future Research Needs

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This chapter reviews several general research needs in the area of speech perception tests. Specific examples from the areas of *hearing aid selection and adjustment* and *speech perception training applications* are provided. Models of speech perception should direct our development and interpretation of speech perception tests. Edited-natural and synthetic speech should be used to address specific questions concerning speech perception among individuals who have an impairment. More knowledge is needed about the effects of auditory and visual noise on speech perception performance. Virtual reality or other simulations may afford some assistance in providing accurate approximations of everyday acoustic environments. A variety of reliable, sensitive, and efficient tests are needed. Closed set tests could help in this area. Speech perception tests should assist in the selection, adjustment, and evaluation of hearing aids.

Speech perception tests can also be used to determine if specific clients could benefit from auditory or speechreading training, and if so, they could assist in the identification of appropriate training stimuli.

Speech perception is fundamental to the communication process, and therefore, its evaluation should be the cornerstone of audiological rehabilitation. In this chapter some general research needs that should contribute to the development of better clinical services in the area of audiological rehabilitation are described. Then some specific examples of speech-perception research needs in the fitting and adjustment of hearing aids, and training applications are provided. As with other chapters in this monograph, we focus on adults with a post-lingual hearing loss.

GENERAL RESEARCH NEEDS

In this section some important research needs that are relevant to general issues concerning the use of speech perception tests in audiological rehabilitation are outlined.

Need to Develop and Utilize a Model of Audiovisual Speech Perception

A model of audiovisual speech perception could help us better understand the processes involved in speech perception. This should place us in a better position to develop tests, to understand their implications, and to plan therapy based on their results (see also Gagné, Chapter 7). Figure 1 shows a general schematic representation of some stages of processing involved in audiovisual speech perception. The physical stimuli undergo some peripheral encoding. At some latter stage, preliminary preprocessing specific to the modality, auditory or visual, likely occurs. This might involve some initial segmentation of the stimulus into some minimal perceptual units. The central integration stage recognizes and comprehends the input from both modalities. This stage uses "higher-level" knowledge about language and the environment. This would include knowledge about the environmental context in which the speech is being perceived, and previous knowledge about the topic of conversation. The model could be expanded to include tactile and other inputs. Several more complete models exist (e.g., Boothroyd, 1993; Braida, 1991; Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Massaro, 1987; Stevens, 1975). Models should not only help explain observations, but also provide ideas for new areas of speech perception testing.

A complete audiological evaluation of the client may need to include all stages of processing, and it may be desirable to determine how well different stages are integrated. It is important to ensure that our speech-perception tests can isolate different attributes of the speech-perception process.

We should use our models of speech perception to guide us in diagnostics and therapy. For example, many have argued that speech is *detected, discriminated, recognized,* and *comprehended.* However, discrimination, the ability to

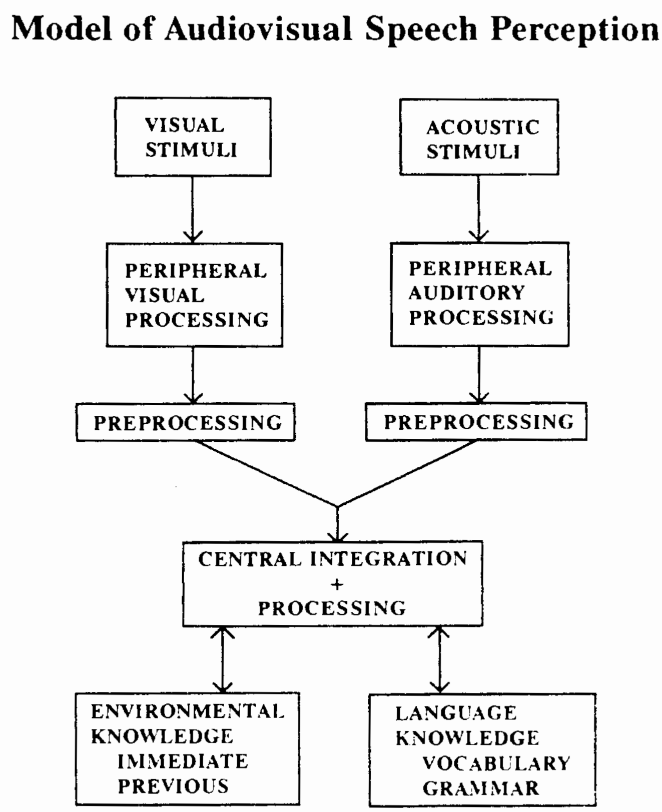

Figure 1. A schematic representation of a simple model of audiovisual speech perception.

hear a difference between two or more sounds, is not essential in our model of speech perception. Although discrimination between sounds can be accomplished, it may not be part of the normal process of speech perception. Therefore, we might question its relevance to speech perception, and whether it should be included (or even considered) in speech-perception training programs.

In this chapter the focus is on speech *recognition* testing. It is important to isolate recognition from comprehension. A sensory aid may be able to provide sufficient information for speech to be recognized. However, the speech stimulus may not be comprehended because of the client's limited cognitive processing abilities. The speech recognition tests must be age and language appropriate or they may provide misleading results, particularly when they are used with children (Boothroyd, 1991; Tyler, 1993).

Our model will also influence the units of speech stimuli that are chosen to evaluate speech perception performance. Table 1 shows a range of stimuli commonly used, from phonemes to paragraphs. Testing with each unit has its own advantages and disadvantages, and the most appropriate unit will depend on the process within the model that is being assessed. *Phoneme* testing provides valuable information about the kinds of speech features perceived. Assessing a client's *recognition skills* can best be accomplished with phoneme and word tests, although these tests miss the rapid nature of speech. Assessing *comprehension* can best be achieved with sentence and paragraph tests. Sentences and paragraphs can be used to test recognition (e.g., Cox, Alexander, & Gilmore, 1987) but caution must be used to account for the effects of language competencies and contextual cues. That is, responses could result from misperceived words or from inadequate knowledge of the language or the environment in which the stimuli are presented.

Some very important work has begun to examine the relationship among the various linguistic units of speech (e.g., phonemes, words, sentences) and speech-perception performance (e.g., Boothroyd & Nittrouer, 1988; Bronkhorst, Bosman, & Smoorenburg, 1993; Rabinowitz, Eddington, Delhorne, & Cuneo, 1992). These researchers quantified the relationship among different units of speech in an attempt to account for the internal redundancies within a word, or within a sentence. A better understanding of the effects of linguistic redundancies on speech perception may result in a reduction in the number of tests needed in a complete audiological evaluation, and in the identification of the relative importance of factors in the perceptual strategies employed by an individual. For example, results from a sentence test could be used to predict performance on a word test and to isolate the client's ability to utilize grammatical information.

Table 1

A Comparison Between Some Different "Units" for Testing Speech Perception

Stimulus	Example	Disadvantages	Advantages
PHONEME	"hid, head, had . . ." or "ipi, imi, ifi . . ."	Perceived poor face validity, but absence of context effects.	Examine phonetic errors, use of closed-set, no assumptions about vocabulary.
WORD	"Hot, baseball"	Some words may be overused and not truly open-set.	High face validity, that is, a natural speech perception event.
SENTENCE and PHRASE	"He went to the store."	Influenced by knowledge of linguistic factors, and requires more time to administer and score.	High face validity, and includes coarticulation effects.
PARAGRAPH	"He went to the store. Inside, he bought three candy bars. He ate one and gave the others to his friends."	More time to administer, familiarity with topic possible confounding factor.	Highest face validity, rapid rate of speech is tested.

Need to Utilize Altered-Natural and Synthetic Speech

Most tests and training procedures use naturally produced speech. However, altered-natural speech or synthetic speech could be beneficial in some applications. Altered-natural speech is naturally produced speech that has been modified, usually with a computer editing program or with analogue filtering. The usefulness of synthetic and edited-natural speech has not been fully appreciated or utilized, perhaps because these speech materials cannot be presented easily "live voice" and often they require extensive time to prepare. However, the use of these speech materials facilitate the study of feature perception in a variety of controlled acoustic contexts. Computer programs that make it possible to change the amplitude of individual formants and the duration of particular speech segments are presently available (e.g., Jamieson, 1992; Montgomery & Edge, 1988; Revoile, Holden-Pitt, Edward, & Pickett, 1986). Table 2 outlines some of the advantages and disadvantages of the different types of stimuli that can be used to evaluate speech-perception performance. Research using synthetic and natural speech tokens that have been edited to investigate the perception of specific speech features may help understand the distortions introduced by hearing loss and provide insights into new training approaches (e.g., Revoile et al., 1986; Tye-Murray, 1992; Tye-Murray, Tyler, Bong, & Nares, 1988; Tyler, Opie, Fryauf-Bertschy, & Gantz, 1992). For example, in a rehabilitation session, the amplitude of the second formant frequency could be amplified for clients who have difficulty perceiving spectral information at higher frequencies. Alternatively, adjacent formants could be attenuated. In testing, the amplitude or the duration of frication could be increased until it is perceived by the client (Tye-Murray, Tyler, Lansing, & Bertschy, 1990). Categorical perception studies provide another example of the use of synthetic speech materials (e.g., Dorman, Hannley, McCandless, & Smith, 1988; Liberman et al., 1967). Use of these materials could provide useful clinical data about the kinds of cues individuals use to understand speech. Unfortunately its use has been largely overlooked in audiological rehabilitation.

Table 2
Differences Between Natural and Synthetic Speech Stimuli

Speech Stimulus	Advantages	Disadvantages
NATURAL	Realistic	Too many cues, variations from talker to talker
EDITED NATURAL SPEECH	Somewhat realistic, some control of parameters	Requires more sophisticated software
SYNTHETIC	Control acoustic characteristics	Sounds unnatural, may be unrealistic, can require much time to generate items

Table 3

Typical Listening Situations and Some Relevant Communication Factors

Listening Situation	Visual Cues Available	Background Noise	Localization Required	Reverberation a Consideration	Distance to Speaker (meters)
One on one	Yes	Sometimes	No	No	1.5
Small group	Yes	Sometimes	Yes	No	3
Large room	Reduced	Usually	Yes	Yes	15
Television	Sometimes	Sometimes	Sometimes	No	3
Telephone	No	Sometimes	No	No	.001 (minimal)
Car	Reduced	Yes	Sometimes	No	1
Workplace	Sometimes	Usually	Yes	Possibly	2
Public address systems	No	Yes	Yes	Yes	30

Research is needed to design speech or speech-like stimuli that focus on very specific aspects of speech perception. The findings of those investigations could provide some direction for the clinical adjustment of sensory aids or for therapy.

Need to Define and Utilize Typical Listening Situations

There is a great need to incorporate typical listening situations in our evaluation of speech perception performance. Using a known, controlled, and repeatable stimulus is important, but we should not restrict ourselves to testing in quiet or in speech-shaped noise. Table 3 describes some of the important parameters associated with communication in some typical situations. It may be possible to simulate particular listening environments in which the client experiences some speech perception difficulties. Computer processing of speech and noise can simulate different reverberation times. Different audiovisual tests and background noise, that are appropriate for the subject being tested, can be used. This might require, for example, the client to obtain an audio recording of the noise present in the work or home environment and bringing it into the clinic for digitization and inclusion into the evaluation. Speech should be tested at different overall levels and audiovisual tests should be administered at varying distances.

There is a need for more information about the temporal and spectral characteristics of noise, and the signal-to-noise ratios of various situations in which individuals with a hearing impairment typically communicate. For example, the temporal and spectral characteristics of a noise often change dramatically from minute to minute. Using an atypical constant noise source for the evaluation of speech perception may artificially make the test easier than it would be in the real world. Knowledge about the dynamic characteristics of "background" noise should be important for designing noise reduction hearing aids and compression-circuit time constants, for selecting conditions to evaluate hearing aids, and for defining the acoustic conditions under which speech perception (and production) training should occur.

We need more information about the visual facial cues that supplement speech perception. Most audiovisual (and auditory) tests are limited to one or two talkers, completely ignoring the diversity of cues provided by different talkers in natural communication situations. Furthermore, little is known about the different kinds of background visual noise and the strategies people use to ignore visual noise. For example, although it is known that bright light behind the talker can be distracting to the listener, there is little information concerning the distracting effects of different types and speeds of movement competing for the visual field of the listener. Information about both visual and acoustic noise are needed in environment specific situations, such as might occur when using the television and telephone. For example, Gagné, Masterson, and Munhall (1992) showed differences in visual speech recognition, across and within talkers, between conversational and clear speech.

New technology should facilitate the simulation of controlled, realistic situations (e.g., Walden, Montgomery, & Prosek, 1987). Multiple loudspeakers and laservideo discs (Dempsey, Levitt, Josephson, & Porrazzo, 1992; Hanin, Boothroyd, & Hnath-Chisolm, 1988; Tye-Murray et al., 1988) should be explored to create better simulations. Digital recording of moving video images directly onto a computer that can easily be edited and integrated with sound recordings will open up many new opportunities in audiological rehabilitation. Three-dimensional computer visual moving images with visual and acoustic "views" linked to the client's body and head position, known as "virtual reality," could be used to test audiovisual speech perception in an interactive context, or moving holographs of real talkers can produce lifelike images of real people viewed at different angles. Less expensive visual images recorded with dual cameras and viewed with "3-D" glasses could also be exploited. The computer game industry could facilitate the application of this technology and make it economically practical to implement into clinical environments.

Need to Develop Sensitive and Reliable Clinical Tests

One of the most important needs in audiological rehabilitation is for sensitive, reliable speech-perception tests (see also Gagné, Chapter 7). The tests need to measure real differences among hearing aids, and changes in performance brought about by speech perception training. The reliability of speech-perception tests can be improved if the number of items in a test is increased (Thornton & Raffin, 1978). Testing time can be shortened with computer-controlled testing procedures, and the sensitivity might be improved by the use of more analytic analysis techniques (see below). Consequently, more time could be allocated to selecting and adjusting hearing aids (Tyler, 1991).

Open-set testing is often easier and more efficient to administer than closed-set tests. It also approximates more closely realistic listening situations, and is therefore important for audiological rehabilitation. Although most of speech-perception testing is accomplished in an open-set response format, there are some important advantages to closed-set testing that are not being exploited, particularly when they are implemented under computer control. First, speech perception tests could use automated scoring procedures which would make it possible to proceed rapidly through a list of test items. The foils can be displayed on a touch-sensitive computer monitor. The client can respond by touching the word (or with children, the picture) as soon as the stimulus is identified. Not having to repeat the word is advantageous for clients who display defective articulation patterns. An audiologist does not have to listen, recognize, or write down the listener's response. The computer can automatically score the subject's responses and present the next stimulus. Such automation is not easily implemented with open-response sets. Machine speech recognition can be explored as a clinical tool in the futnre. Presently, the problems include a requirement of extensive training, the recognition can be highly speaker dependent, and recognition is primarily limited to relatively small stimulus sets.

A second benefit of closed-set tests is the ability to easily examine the pattern of errors. This is facilitated when the responses are entered directly into a computer. A confusion matrix, tabling the stimuli against the responses, can be generated to allow for a systematic examination of the errors made by the client. When the stimuli can be categorized according to features, as is the case for vowels and consonants, an information transmission analysis (Miller & Nicely, 1955) and sequential information transmission analysis (Wang & Bilger, 1973) can be performed. These analyses techniques facilitate the quantification of speech features that are perceived and their relative importance. Research is needed to develop clinical protocols that can bring the advantages of closed-set speech perception tests into clinical settings.

RESEARCH NEEDS IN HEARING AID SELECTION AND ADJUSTMENT

Table 4 outlines three important questions related to the selection and fitting of a hearing aid. Speech-perception testing should have an important role in answering all of these questions.

Table 4

Uses of Speech-Perception Tests When Considering Issues Related to Hearing Aid Selection

Application	Appropriate Comparison
Selecting the signal processing strategy	1. Predict desired signal processing from audiogram or psychoacoustic data. 2. Compare all possible signal processing methods. 3. Adaptively compare signal processing methods.
Adjusting the signal processor	1. Predict adjustments from audiogram or psychoacoustic data. 2. Compare all possible adjustments. 3. Adaptively compare few adjustments.
Determining if expected benefit has been obtained	1. Compare to group of clients with similar hearing loss using similar device and signal processing.

Selecting the Signal Processing Strategy

There are now a variety of signal processing strategies available, and speech-perception tests could help decide which should be used for a particular client (see also Seewald, Chapter 5). Signal-processing strategies include output limiting (clipping or output compression), wide-range compression or "linear" amplification, the number of processing channels in a multiband hearing aid, and different noise reduction circuits, to name a few.

There are at least three ways to systematically determine the appropriate signal processing strategies for a client: (a) audiometric and psychoacoustic performance, (b) performance on all possible signal-processing strategies, and (c) performance of a few of the possible strategies using adaptive techniques.

Predicting speech-perception performance from audiometric and psychoacoustic tests is difficult because of large individual differences (Crandell, Henoch, & Dunkerson, 1991; Seewald, Chapter 5) and the number of variables that might contribute to performance. For example, it may be that clients with a precipitous high-frequency hearing loss at 3000 Hz benefit from a two-channel hearing aid, and those with a gradual loss benefit from a three- or four-channel hearing aid. The articulation index (e.g., Humes, 1991; Mueller & Killion, 1990; Pavlovic, 1991) is an important step to quantify the amount of speech information that can be detected. However, the articulation index does not accurately predict the performance of all individuals with a hearing-impairment, and further research is needed to account for more of the individual differences that have been observed among individuals with similar audiometric configurations. In addition, the articulation index formula requires a modification so that the score is reduced when the level of speech is too loud, although increasing audibility, this makes the speech unpleasant to hear. Psychoacoustic tests of temporal, frequency, and intensity resolution have been able to show moderate correlations to speech recognition (e.g., Dreschler & Plomp, 1985; Lutman & Clark, 1986; Rosen & Fourcin, 1986; Stelmachowicz, Jesteadt, Gorga, & Mott, 1985; Tyler, 1986). The results of those tests have the potential to be used by the audiologist in prescribing specific types of signal processing strategies that could overcome perceptual deficits. Again, more research is needed to account for individual differences. It may be that the use of more speech-like stimuli (including edited-natural and synthetic speech) will be helpful (e.g., Revoile, Kozma-Spytek, Holden-Pitt, & Pickett, 1991; Van Tasell, Greenfield, Logemann, & Nelson, 1992).

Another approach to the selection of an appropriate processing strategy is simply to examine the client's speech perception ability with all possible signal processing options. This could be done easily if the number of options is small. For example, the performance of subjects wearing hearing aids that use peak clipping versus output compression could be compared. Testing all possible strategies is the most comprehensive approach to selecting the "best" signal processing strategy. It could be problematic, however, if there are a large number of alternatives. If the "best" strategy is predicted from audiometric or psychoacoustical data, it is always difficult to know if all the relevant predictor variables have been considered. Research will be needed to determine the most sensitive tests for different signal processing options. For example, a high signal level test, perhaps in high levels of background noise, might be needed to select between output limiting options. Gatehouse (1992) has noted that some signal processing strategies might require several weeks or months before the particular merits of a strategy are achieved. Research is needed to determine if the relative differences among signal processing strategies observed among individuals with no listening experience change after some auditory stimulation. If they do, paradigms for clinical trials that consider this acclimatization effect will have to be developed.

The third approach requires that only a few signal processing strategies with a higher likelihood of success be evaluated. This approach would be desirable where it is impractical (e.g., because of time constraints) to try all possible strategies. An adaptive algorithm may be used. This is a procedure for arriving at a target based on how the client responds. The standard clinical audiometric threshold procedure (Hughson & Westlake, 1944) is an example of a procedure where the attenuation step size changes adaptively. For example, an adaptive procedure could be used to determine the optimum number of bands in a multichannel hearing aid.

Adjusting the Signal Processor

Each signal-processing strategy typically has several variables that have to be adjusted. For example, the options that require adjustment could include different compression thresholds, release time characteristics, the frequency response, and the frequency bandwidths of a multichannel hearing aid. Having a range of settings available for each option is desirable, because optimal settings will vary across individuals and listening situations.

The above-mentioned approaches described for selecting among signal-processing options can also be used for adjusting the signal processor, including, predicting performance from audiometric and psychoacoustical measures, trying all possible options, and using adaptive tests. In this instance, performing speech perception tests with all possible options is less applicable, because a large number of settings may be available (e.g., the threshold for wide range compression). However, adaptive strategies are more applicable, because only a limited number of choice settings will be compared. These adaptive strategies involve systematically adjusting one or several parameters, measuring speech-perception performance at those settings, and then further adjusting the hearing aid based on these results (e.g., Kuk, 1992; Lawson, Finley, & Wilson, 1990; Levitt, 1992; Neuman, Levitt, Mills, & Schwander, 1987). More research is needed to develop efficient adaptive procedures that make use of various types of speech stimuli.

Determining if Expected Benefit has Been Obtained

Typically, a hearing aid is deemed satisfactory if it is purchased or if the performance of the aided condition exceeds that of the unaided condition. However, it is important to determine if the client has obtained the expected benefit from the device. Thus, a comparison of speech perception could be made between the client and a group of clients with a similar hearing loss who use a similar hearing aid. Even when a client benefits from a hearing aid, it may be that even greater benefit could be obtained with different signal processing or with better adjustments.

Unfortunately, those data are not readily available. However, as new devices are evaluated in field trials, data obtained from groups of clients should be collected. In part, this should be the manufacturers' responsibility. The manufacturers, or independent investigators, could publish the results from a multicenter hearing aid trial. The important client biographical and audiometric data should be presented, as well as the individual performance on speech perception tests. This information could be used to predict those clients who will benefit the most from newly designed hearing aids (Tyler, 1991). The lack of clinical trials makes it difficult to determine if a new signal-processing strategy improves performance, and what performance levels can be expected with different populations. Furthermore, when hearing aids that have not been adequately field tested are marketed (and claims are made that they can accomplish things that they cannot), their disappointing failure may deter potential hearing-aid users from purchasing future hearing aids.

RESEARCH NEEDS IN TRAINING APPLICATIONS

There are several ways that speech-perception testing could be applied in training (see also Gagné, Chapter 7). In this section, we identify some specific areas, show examples, and outline future research needs.

Is Training Needed?

Although many clients will benefit from training, it is also likely that some will not. It is important to establish whether training will improve performance before therapy begins. Speech-perception tests should help in this area.

There are two ways one could decide if a client is a good candidate for therapy. One way is to compare the client's performance to a group of similar clients. The other way is to begin some preliminary therapy and determine its effectiveness.

If a client's performance falls below that of a group of matched clients, then

Table 5

Uses of Speech Perception in Training Applications

Training Application	Appropriate Comparison
Is training likely to be beneficial?	1. Compare individual performance to performance of a group with similar characteristics. 2. Evaluate the effectiveness of some preliminary training.
What stimuli should be trained?	1. What stimuli are misperceived? 2. With which stimuli does subject show most improvement? 3. Which stimuli have the greatest effect on perception?

Note. These considerations are appropriate for all training applications, including environmental sound perception, speech-perception, interactive communication, and audiovisual perception.

therapy might be helpful. For example, if a 45-year-old client with a moderate noise-induced hearing loss obtains 40% correct on a speech-perception test and the average score of similar clients is 75% correct, then the former client might be an excellent candidate for audiological rehabilitation. Research is needed to develop a data base of performance from large groups of clients, preferably for different subgroups of age, degree of hearing loss, length of deafness, etiology, and perhaps other variables.

Another approach is to perform some preliminary therapy, and determine if performance improves. For example, even with a client whose speechreading ability is within the typical range of performance on a given test, it may be that additional therapy could be beneficial. Research is needed to establish effective preliminary training algorithms (including the necessary duration of the trial for each individual), along with sensitive speech-perception tests.

In the following subsections, we provide examples of how a client's data could be compared to group data in order to determine the need for training.

Auditory training. One way to assess the ability of the client to utilize the auditory cues available might be to compare the performance of two distinct speech-perception tests that utilize different types of auditory cues. This is based on the reasonable assumption that auditory perception is based on some limited set of processing abilities. The results obtained from different tests will emphasize, to a greater or lesser degree, these different abilities. We can determine the expected relationship between different tests by studying group performance. An individual's scores can be compared to the group performance to determine if the individual is not utilizing certain auditory abilities in a manner expected based on the group performance. Comparisons could be made among vowel, consonant, word, sentence, and even environmental sound perception. The tests that are used should be independent of language and cognitive factors. The example here compares the perception of consonants to the perception of environmental sounds. Exploring this relationship assumes that some of the basic auditory cues used for environmental sound recognition reflect the same cues needed to recognize consonants. Figure 2 shows that cochlear-implant clients who obtain higher consonant recognition scores also obtain higher scores on environmental sound recognition. However, there is some variability across clients. Those clients who fall towards the top of the cluster perform relatively better on environmental sound recognition than on consonant recognition. They might benefit from speech-recognition training. Their environmental sound perception scores suggest that they are receiving ample auditory information, but their low speech-recognition scores suggest that this information is not being utilized as well as it could be for speech recognition. Conversely, clients whose data points fall on the lower portion of the cluster perform relatively better on consonant recognition than on environmental sound recognition. It could be argued that they require training on environmental sound perception. Research is needed to establish the expected relationships among these different tests of auditory perception (including vowels, phonemes, sentences, and music), and to identify

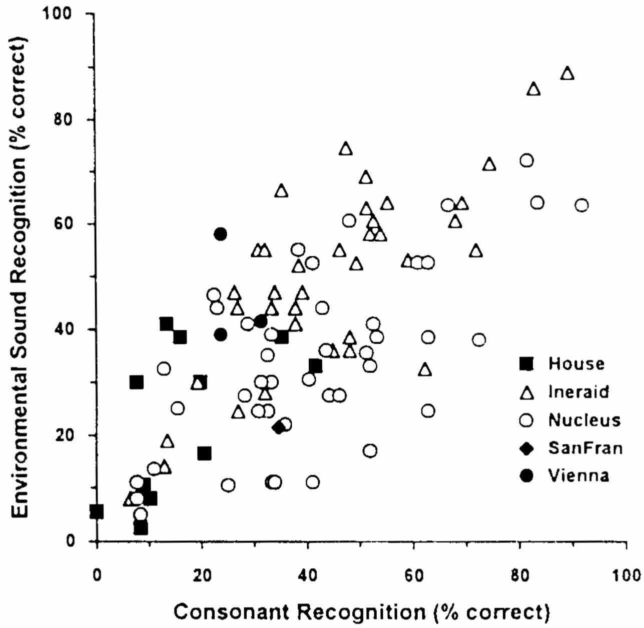

Figure 2. The relationship between the perception of consonants in nonsense syllables and environmental sound recognition in multichannel cochlear implant clients. Generally, clients who score higher on one of these tests, scores higher on the other, because both tests are a general indication of the amount of auditory information received. Clients whose data fall at the top of the cluster perform better on the environmental sound tests, and might benefit from consonant recognition training. Clients whose data fall at the bottom of the cluster perform better on consonant recognition, and might benefit from environmental sound training.

the clients that could benefit from speech perception training.

Speechreading training. Next we compare the visual recognition of speech from the individual client to a larger group. Clients who are poor speechreaders might benefit from training.

Figure 3 displays the speechreading performance of several individuals with a profound post-lingual hearing impairment on a consonant speechreading test. Data such as these can be used to compare the client's speechreading performance to that of others. For example, a score of 40% correct on the consonant recognition test is in the top 25% of clients who have taken the test. A client who scores this well may not require training. A score of 25% correct is in the lower 25% of clients, such a client might very well benefit from speechreading training (see also Gagné, Chapter 7). Research is needed to establish normative values for audiovisual speech perception, and to determine which populations respond better to therapy.

Another important question involves the ability of the clients to integrate

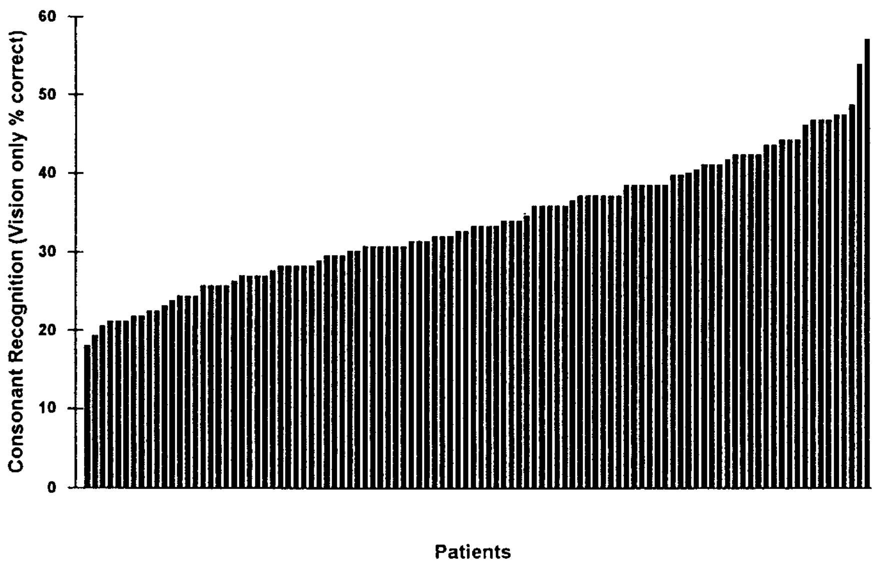

Figure 3. The lipreading performance of cochlear implant clients on the Iowa Consonant Recognition Test, administered in vision only condition.

auditory and visual information. It would be of interest to be able to predict how much improvement in speech perception performance should be expected from a client when the stimuli is presented audiovisually rather than auditorally or visually separately (Massaro, 1987). One approach to this is shown in Figure 4, again using clients with cochlear implants. Here, the amount of auditory information received is compared to their audiovisual enhancement (calculated as percentage of the possible enhancement: [audiovisual score minus vision score] divided by [100 − vision score] times 100; Tyler, 1991; see also Montgomery, Chapter 16). As expected, as the amount of auditory information conveyed increases, the audiovisual enhancement score increases. However, there is also a great amount of individual variability. Clients who fall close to the horizontal axis make less use of auditory information than clients who are well-above the horizontal axis. This former group of clients may be among those who would benefit the most from audiovisual training. Research is needed to quantify the amount of audiovisual enhancement for different degrees of hearing loss.

These examples demonstrate ways in which speech-perception testing can be applied directly to clinical decisions in audiological rehabilitation. Research is needed to establish normative data for different populations, and to determine the practical utility of these suggestions.

Which Stimuli Should be Used for Training?

It is important to decide which stimuli should be trained to increase the effi-

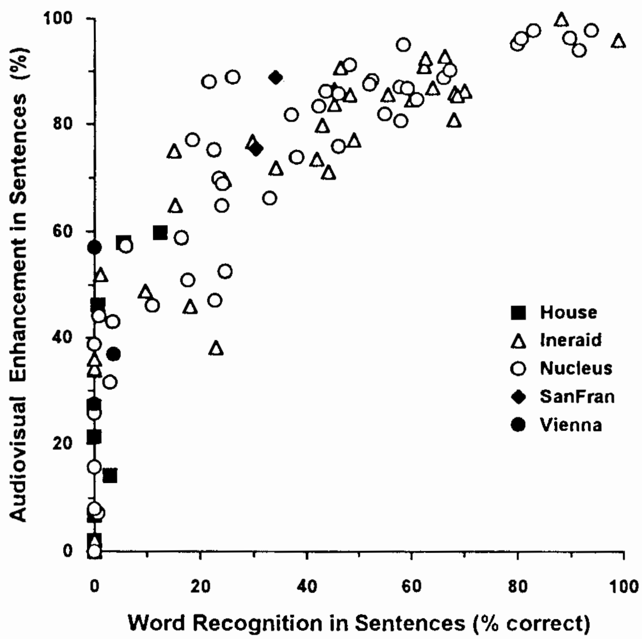

Figure 4. The relationship between the perception of words in sentences in an auditory alone condition and the audiovisual enhancement (calculated as percentage of the possible enhancement: [audiovisual score minus vision score] divided by [100 − vision score] times 100; Tyler, 1991). Generally, clients who fall at the bottom of the cluster are receiving less audiovisual enhancement than the average subject with that amount of auditory recognition. These subjects might benefit from audiovisual integration training.

ciency and cost-effectiveness of training. When analytic training is pursued it is important to learn which phonemes are misperceived and in which context these misperceptions occur. Both vowel and consonant recognition tests that would provide information about phonetic errors are available (Levitt, 1992; Owens, Benedict, & Schubert, 1971). For example, tests of "hid, head, had . . . or bit, bat, bad," and "ama, apa, afa . . . or fa, sa, ta" are frequently used in research (Braida, 1991; Summerfield & McGrath, 1984; Walden, Montgomery, Prosek, & Hawkins, 1990; Wang & Bilger, 1973). These tests need to be adapted for clinical use. It would be helpful if some tests provided detailed context-specific information. The context could include phonetic, word, or phrase boundaries, as well as talking rate, talker fundamental frequency, and background noise levels. These variables may influence performance differently across clients. Once the error patterns are established, it might be possible to determine which stimulus would be the most appropriate for training. Preliminary training should be attempted using different contexts, and speech-perception tests used to evaluate effectiveness (see Montgomery, Chapter 16). In addition, exploring the preliminary success of different training strategies could be helpful to determine the hierarchy of training approaches or materials.

CONCLUSIONS

Speech perception is critical to communication, and its direct measurement should be a cornerstone of audiological rehabilitation. We have outlined some general research needs in the application of speech perception to audiological rehabilitation. Future research should utilize models of speech perception, and should benefit from the inclusion of synthetic speech and edited-normal speech as test materials. We also need to define typical communication environments more precisely, including the varying nature of background auditory and visual noise. Closed-set speech-perception tests could help in the quest for reliable, sensitive, and efficient tests.

There are many ways in which speech-perception tests can contribute to hearing aid selection and adjustment. They should be used to select the signal processing strategy, to adjust the signal processor optimally, and to determine if appropriate benefit has been achieved by the client. Research is needed to develop appropriate tests, to gather normative data, and to explore these applications.

Speech-perception tests also have a great potential to contribute to training applications. They can be used to determine if auditory or speechreading training is needed, and which stimuli would be most appropriate for a particular client. Research in these areas will become even more important as we must justify the cost-effectiveness of our work.

This is an exciting time in the application of speech-perception tests to audiological rehabilitation. Computer-based audiovisual simulations provide the opportunity for realistic test environments to be produced in controlled situations with automated scoring of responses and automated sophisticated response analysis.

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