Chapter 8

Research in Auditory Training

Peter J. Blamey and Joseph I. Alcántara
University of Melbourne

Speech perception and communication can improve as a result of experience, and auditory training is one way of providing experiences that may be beneficial. One of the most important factors influencing the effectiveness of auditory training is the amount of experience the client already has. Other factors include the severity of the hearing loss, the sensory device used, the environment, personal qualities of the client and clinician, the type of training, and the type of evaluation used. Despite a long history of clinical practice, the effects of these factors have been investigated in few controlled studies. Even in special cases where training has an obvious role, such as adults using cochlear implants, there has been little objective comparison of alternative training methods. One reason for this is the difficulty of carrying out definitive experiments that measure changes in performance over time in the presence of many confounding variables. These variables may also help to explain the apparently contradictory results that can be found in the literature on auditory training and in the diverse points of view expressed by practicing clinicians. Issues and methods appropriate for research in auditory training among adult clients are discussed with reference to the needs of modern clinical practice.

THE NATURE OF AUDITORY TRAINING

The purpose of this chapter is not to provide an auditory training manual, but to introduce the basic ideas behind training techniques and indicate how the effectiveness of auditory training might be improved by research. In keeping with the general aims of this monograph, the discussion relates mainly to the auditory training of adults with adventitious hearing loss. Occasional reference is made to tactile training to illustrate research methods because the authors' experiences of training studies have been gained primarily with a tactile speech processor used by children and adults.

Definitions of Auditory Training

Before the existence of wearable electronic hearing aids, the two terms "aural rehabilitation" and "auditory training" were almost synonymous because the additional procedures now included in audiological rehabilitation were available only in a rudimentary form, with the exception of lipreading training. The first electronic hearing aids were called "auditory trainers" because they were too bulky to be carried around as an aid to everyday communication. Hearing aids are no longer used only for training so that it is no longer appropriate for the measurement of hearing and the fitting of hearing aids to be considered a part of auditory training. In a modern model of audiological rehabilitation (e.g., see Alpiner & McCarthy, 1987, p. 10) auditory training is a relatively small component of the global rehabilitation process. Within this modern framework, it is possible to question the role of auditory training: Is it effective? Is it necessary? BUT, before these questions can be tackled, we must determine what remains within the scope of auditory training. Various definitions of auditory training have appeared in the literature:

> A development and/or improvement of the ability to discriminate various properties of speech and non-speech signals, such as loudness, pitch, and rhythm. (Goldstein, 1939)

> Teaching the child or adult who is hard-of-hearing to take full advantage of sound cues. (Carhart, 1960, p. 373)

> A systematic procedure designed to increase the amount of information that a person's hearing contributes to his total perception. (Sanders, 1971, p. 205)

> Creation of special auditory communication conditions in which teachers and audiologists help hearing-impaired children acquire many of the auditory speech perception abilities that normally hearing children acquire naturally without their intervention. (Erber, 1982)

Goldstein chose a narrow definition emphasizing discrimination without requiring sounds to be used in a meaningful way. Carhart emphasized the use of teaching to increase the information received. Sanders' definition is similar to Carhart's, but broader because of the use of the word "procedure" rather than "teaching." The fitting of a hearing aid is a systematic procedure that would fall within Sanders' definition but not Carhart's. Erber's definition covers most of audiological rehabilitation. The definition used in this chapter is: *Auditory training is the use of instruction, drill, or practice designed to increase the amount of information that hearing contributes to a person's total perception.* This definition is sufficiently precise to allow the questions raised above to be posed in an unambiguous fashion, and not so restrictive that it excludes procedures of current interest. It should be understood that the effectiveness of auditory training is not independent of other factors in the client's environment. For example, the creation of special communication conditions, as mentioned by Erber, may be necessary to achieve the maximum benefit from auditory training. The environment and characteristics of the client will be considered as important factors influencing training, but not as parts of the training.

Aims of Auditory Training

Increasing the information that hearing contributes to perception is a very general aim. Auditory training programs usually have more specific aims, chosen after considering the specific requirements of the client. A person who has never heard before will need to develop more basic hearing skills than an adult with a moderate hearing loss of short duration. These basic skills might include discrimination of pairs of vowels or consonants, or identification of items from a small list of words. A person with a hearing-impairment who wishes to play a musical instrument might benefit from exercises in the discrimination and recognition of short sequences of notes with different rhythm and melody patterns. A person fitted with a new hearing aid may benefit from instruction and practice in recognizing sounds through the aid. This practice might take the form of a conversation with the audiologist in which different sounds are produced and discussed. Alternatively, a more structured approach may be used in which sounds are introduced systematically or the new hearing aid user is trained in the recognition of sentences. Instruction and practice in the use of context to derive meaning may be appropriate for more experienced hearing aid users. Each example above falls within our definition of auditory training with the general aim of increasing the information obtained from hearing, but the specific aims are different.

The selection of appropriate short-term goals is an important step in achieving an effective auditory training program. Several methods for matching the specific goals of the training to the needs of the client have been suggested. For example, Alpiner and McCarthy (1987) reviewed a large number of questionnaire-based assessment scales, Garstecki (1981) advocated an initial evaluation to identify "baseline" conditions under which the client achieved a high level of speech recognition, and Lubinsky (1986) proposed the use of an information-processing model of speech perception to determine the stages of processing that limit the client's use of hearing.

The Need for Auditory Training

It has often been claimed that humans are predisposed to learn without formal training (Lenneberg, 1967) and it is important to acknowledge the role of everyday experience in learning and maintaining skills. Whether people have normal or impaired hearing, their auditory skills are the product of their past experience and depend on the usual demands that they place on their hearing. It is "untrained" learning like this that enables normally-hearing children to acquire auditory skills initially. Even so, it must also be acknowledged that some experiences and environments encourage learning more effectively than others. The special conditions provided by the mother-child relationship in infancy (Brown, 1977) might be regarded as a naturally occurring auditory training program and many programs for hearing-impaired children have been modelled on this relationship (Ling, 1984).

The use of auditory training with adults does not deny the influence of untrained learning. Instead, it is the function of training to increase the learning rate and/or to raise the final level of performance above the level achievable with untrained learning. The stable level of auditory information processing that can be achieved through untrained learning depends on several factors. Those factors will be discussed below. Some of them may be altered by auditory training to allow further learning to occur.

Potential Recipients of Auditory Training

Potential clients fall into three categories: people who wish to learn additional auditory skills, such as a new language or a musical instrument; people whose hearing condition has changed recently; and people whose auditory skills are stable but inadequate to meet their communication needs. For the first group, training is required if the client's usual experience does not include sufficient exposure to the new auditory signals for untrained learning to take place. For the second group, changes might be negative such as a rapid loss of hearing, or positive such as the fitting of an improved hearing aid. Some clients, such as cochlear implant recipients, will have a clear need for training in order to become familiar with an auditory signal that is quite different from what they have been accustomed to. At the Royal Victorian Eye and Ear Hospital Cochlear Implant Clinic, all postlinguistically deafened adult implant users undergo a 10-week postoperative rehabilitation course that includes auditory training (Brown, Dowell, Martin, & Mecklenburg, 1990). Depending on the client's level of performance, the materials and aims of training vary from recognition of phonemes and closed sets of words, to recognition of open-set sentences over the telephone. In other situations, such as clinics dealing with mild hearing losses, auditory training may be required only for a minority of clients, or may be limited to pragmatic training.

Potential clients in the third group are most likely to be those whose hearing condition has been stable for several years, and whose hearing impairment is severe. The majority of this group will probably be elderly people. Crandell, Henoch, and Dunkerson (1991) have recently reviewed the literature on speech perception and aging. They point out that the physiological origins of speech recognition difficulties in this group are uncertain, and elderly listeners with similar audiometric configurations may demonstrate widely varying degrees of speech recognition performance in adverse listening conditions. These variations are presumed to be the result of multiple factors, including the loss of pure-tone sensitivity, deficits in suprathreshold auditory processing, and/or cognitive processing. Crandell et al. (1991) suggest that new cost-effective clinical procedures are required to identify the mechanisms responsible for speech-recognition difficulties so that appropriate amplification systems and rehabilitation programs can be provided. Whether auditory training is an appropriate rehabilitation strategy for this group is unresolved (Ross, 1987). In his review, Ross was careful not to overlook the social aspects of participation in a training program. These aspects include opportunities to meet other people with similar problems, to provide mutual support, and to build self-confidence. The interaction of psychosocial factors and communication effectiveness may be particularly important for elderly people with hearing impairments.

Skills and Knowledge Required for Auditory Speech Perception

It has become common to classify auditory skills into a hierarchy of levels according to the stimuli presented and the response required (e.g., Carhart, 1960; Erber, 1982; Ling, 1991). These levels include detection of sound, discrimination between sounds, identification of sounds from a closed set, recognition of sounds in a wider context (open-set), and comprehension of the meaning of speech. This hierarchy has been used to develop auditory training programs assuming that the client should progress systematically from lower to higher levels. Obviously, the lower-level skills are necessary for auditory speech communication and this is the justification for their inclusion in a training program. However, these lower-level skills are not sufficient for the understanding of speech. For example, it may be possible to learn to detect, discriminate, and recognize environmental sounds without learning skills that will help to understand speech. Some training programs have been criticized for their emphasis on learning the gross properties of environmental sounds, particularly if a high degree of performance is required before starting on speech sounds (Rodel, 1985). In addition to the necessary auditory skills, the understanding of speech requires knowledge of the language and of the world. The phonological, syntactic, and semantic structure of the language must be familiar to the listener in order to understand the message. The listener does not need to have studied grammar, in fact, such theoretical knowledge may not be useful in speech perception at all. The listener does need to recognize which sound combinations form valid words, what sequences of words form valid utterances or sentences, and what the individual words mean. It is a defensible point of view that this knowledge is so interwoven with the processing of auditory signals that they must be learned together. Just as the study of grammar may not be helpful, the learning of individual phonemes or other non-meaningful speech components may not help speech perception much. Auditory and cognitive processing may be so interdependent that they cannot be separated without reducing the effectiveness of the training. This is one of the central issues of auditory training research.

In considering auditory training for adults with acquired hearing loss, it may be assumed that the clients have already learned speech perception skills during childhood. The interdependent auditory and cognitive processes have been learned, but the auditory input has been changed by the hearing loss and its subsequent treatment. In some cases, the cognitive processes may also be affected by disuse or degeneration over long periods of time, or by central damage in some etiologies. Even though the cognitive processing is usually intact it may be necessary for this processing to be engaged for the training of new auditory skills to be effective.

Analogies With Other Types of Training

In most fields of human endeavor it is acknowledged that learning occurs and that practice helps to improve performance. A large body of research into learning and teaching exists and it is appropriate to consider whether the conclusions might be applicable to auditory training. Bode and Oyer (1970) summarized the suggestions of Wolfle regarding the application of learning theory to auditory training:

> First, the distribution of practice should be suitable for the task to be learned. Second, active participation by the learner is superior to passive receptivity. Third, practice material should be varied so that the learner can adapt to realistic variation and so that his motivation during drill is improved. Fourth, accurate performance records need to be maintained in order to evaluate progress and effects of training. Fifth, the most useful single contribution of learning theory is the provision for immediate knowledge given to learners regarding their performance. (p. 840)

One may assume that these guidelines are applied in most auditory training programs for clinical and research purposes. It is also instructive to consider specific examples and their degree of similarity (or otherwise) to auditory training.

Sports training. To become proficient at most sports, it is necessary to practice. Without practice, performance becomes poorer. These statements are self-evident when applied to a sport like tennis, but do they apply to speech perception? One difference between sport and speech perception is in the opportunity for practice. Practice of speech perception is possible at most times and in most places. One requires a partner, but the tennis court and other facilities are not necessary. From this point of view, speech perception is more like walking than tennis. Everyday living conditions include many opportunities for practicing speech perception and walking so most people perform very well without specific training. What happens if these everyday practice opportunities are not available? A complete lack of auditory speech perception practice is rare, requiring total deafness, a profound hearing loss that is not aided, or social isolation. Post-operative scores for cochlear implant patients suggest a slow degradation in performance over the time before implantation. Mean scores for recognition of words in open-set sentences 3 months postoperatively decrease by about 0.5% for each year of profound deafness before implantation (Blamey et al., 1992). The mechanism for this degradation may be a physical degeneration of nerve cells in the damaged cochlea. Degradation of performance in a sport or physical activity through lack of practice appears to occur much more rapidly, and the mechanism is more likely to do with muscles than nerves. At this point, our analogy starts to break down. It is possible to maintain muscle tone and build strength by means of exercise without actually playing tennis. It is not clear whether the performance of auditory nerves in speech perception can be improved without actually perceiving speech. The reader should not infer from this that sports training is solely concerned with physical fitness. Recent research emphasizes that there is a cognitive component involved in all complex movements (Fitts & Posner, 1967), and overall performance on a task can be improved by independent training of this cognitive component (Minas, 1980). The cognitive components include knowledge of the sequence of actions required (Minas,

1980) and the detailed motions of all relevant parts of the body (Newell & Walter, 1981). Auditory training may be similar to the cognitive component of sports training, especially in the light of the strong link between speech production and perception that has been postulated in the motor theory of speech perception (Liberman, Cooper, Shankweiler, & Studdert-Kennedy, 1967; Liberman & Mattingly, 1985). Production and perception have also been shown to be interdependent in training studies such as the one reported by Novelli-Olmstead and Ling (1984). In summary, there are points of similarity between sports training and auditory training, but the differences require one to be cautious in generalizing from one to the other.

Arithmetic teaching. Unlike sports, numeracy and mental arithmetic are not physical activities requiring strength or muscle tone. Like sports, they are not everyday activities and so they require explicit training. Learning arithmetic usually proceeds by stages. One learns some numbers. One learns to count and then to add, subtract, multiply, and divide small numbers. Finally one learns rules that allow generalization to arbitrary sets of numbers. In analogy with speech perception: numbers are nouns, operators are verbs, algebra corresponds to grammar, and equations correspond to meaningful statements. As in the learning of speech and language, the first symbols and statements are learned by repetition and general rules come later. These stages of learning correspond loosely to the preoperational, concrete operational, and formal operational stages of Piaget's theory of intellectual development (Bell, 1978). Addition and multiplication tables are over-learned through drill and repetition. Once over-learned, this knowledge degrades slowly compared to the degradation of physical skills. Thus, the effect of practice on arithmetic skills is a closer analogy to auditory training than sports training. There is no logical necessity to over-learn arithmetic tables because they can be deduced from a small number of axioms. The advantage in over-learning is in speed of calculation and automaticity of the response (Fitts & Posner, 1967, pp. 123-124). Similarly, a message could be derived from a string of phonemes using phonological, grammatical, and semantic rules. However, it is likely to be much more efficient to over-learn sequences of sounds corresponding to common constructions. Over-learning is the result of frequent repetition. Indirect evidence for this type of processing comes from the fact that frequently occurring words are recognized faster and more accurately than infrequent words in speech perception (Howse, 1957). For an acquired hearing loss, over-learned associations between acoustic inputs and their meanings will be disturbed. For mild hearing losses, the disruption may not be sufficient to destroy the over-learned associations. For severe hearing losses, associations may be lost altogether if the phonemes are inaudible, or if sounds with different meanings become indistinguishable. In such cases, it is the function of auditory training and untrained learning to replace the previously over-learned associations with new ones that more closely reflect the listener's altered hearing.

Theories of learning and instruction have been applied extensively to the teaching of mathematics. Bell (1978) refers to the works of Jean Piaget, J.P. Guilford, Robert Gagné, Jerome Bruner, David Ausubel, B.F. Skinner, and others. The author discusses the relevance of these works to specific tasks, such as teaching mathematics in secondary schools. Most of Bell's discussion could be applied to the teaching of language also, however auditory training is not language training. The difference lies in the very important sensory component involved in auditory speech perception which is so basic that it is usually assumed to be fully developed before formal mathematical or language teaching take place. In short, there is a body of theory and experience that can be derived from the literature on the training of cognitive skills, but the researcher must be aware of significant differences between auditory speech perception and other cognitive skills.

Musical training. Musical training actually falls within our definition and illustrates that normally-hearing people can learn from auditory training. After musical training, people may identify musical intervals and chords, complex rhythms, and other characteristics that may have been meaningless to them as untrained listeners. Trained musicians also perform better than untrained listeners on some psychoacoustic tasks (Beckett & Haggard, 1973). Similarly, untrained listeners often improve their performance on psychoacoustic tasks over hours of practice (Cuddy, 1968). These examples indicate that discrimination and identification of sounds can be improved by training, and some habilitationists have suggested that these improvements will lead to improvements in speech perception. Examples of auditory training methods that incorporate the use of music include the Verbotonal System (Guberina, 1972) and an application of the Kodaly music program to train the perception and production of prosodic aspects of speech (Dawson, 1989).

A TAXONOMY OF CURRENT AUDITORY TRAINING PRACTICES

Auditory training methods vary widely because trainers have their own ideas on the effectiveness and importance of training procedures, materials, and styles. It is possible, however, to group training methods into broad categories. This is a necessary step before research can attempt to establish the relative merits of existing training methods.

Analytic Training

A training strategy is said to be "analytic" if it involves breaking speech into smaller components which are trained separately. These components may be syllables, phonemes, or segments of speech that share particular segmental or suprasegmental features. For example, individual sessions might concentrate on the differences between vowels with long and short duration, consonants that are voiced or voiceless, or short sentences with different stress patterns. Usually, the training is carried out using tasks requiring identification of a closed set of items. Two of the attractions of analytic training are the relatively small number of speech features to be trained, and the simplicity of designing and evaluating closed-set identification tasks. The method is based on the premise that comprehension of speech depends on the identification of the component features and phonemes in the message. It is also assumed that ability to recognize speech features and phonemes in isolation carries over into connected discourse. Analytic training tends to concentrate on acoustic cues rather than the meaning of speech, and it progresses from basic cues to more subtle or complex distinctions. Sometimes this is described as a "bottom-up" approach.

Synthetic Training

"Synthetic" training focuses attention on more global aspects of the speech such as the meaning, syntax, and context of the message. Training materials typically include meaningful sentences, phrases, or words and the emphasis is on understanding. Synthetic training is related to "top-down" models of speech perception which postulate that the listener synthesizes possible messages from the context and syntax. The listener then chooses between possible messages by comparing them with the incoming acoustic signal. It is unnecessary to analyse the incoming acoustic signal into small components because larger chunks can be compared with the synthesized words, phrases, or sentences. Synthetic training may include sentence perception (Durity, 1982), word-learning procedures (Brooks & Frost, 1983), question and answer procedures (Erber, 1984), and the speech tracking technique (De Filippo & Scott, 1978). The speech tracking technique may include some analytic training components when non-contextual cues are used to elicit a verbatim response from the client.

Pragmatic Training

In "pragmatic" training, the listener is instructed about how to obtain information necessary for communication by changing the conditions under which the interaction takes place. The aim is to obtain the maximum benefit from existing hearing skills, instead of improving the skills themselves. Factors that a listener with a hearing loss can control to influence the effectiveness of communication include: (a) the level of the signal – it may be controlled by adjusting the hearing aid gain, by adjusting the distance between speaker and listener, or by asking the speaker to talk at a different level; (b) the signal-to-noise ratio – it may be increased by moving closer to the speaker, by standing in the most advantageous position relative to the noise source and the speaker, or by moving to a quieter location; and (c) the context and the complexity of the message – they can be controlled by asking questions and using appropriate repair strategies. Practice in controlling the context and complexity of conversations would obviously be a useful adjunct to synthetic auditory training programs which emphasize the use of contextual and structural information for perception. QUEST?AR (Erber, 1984) and speech tracking (De Filippo & Scott, 1978) are synthetic training techniques that have built-in opportunities for the client to practice some pragmatic skills. Awareness and control of loudness and signal-to-noise ratio will also be relevant to an analytic program since the available acoustic cues depend on these factors.

Eclectic Training

In practice, auditory training programs tend to combine elements of all three strategies described above. One justification for this "eclectic" approach is that each strategy trains a different aspect of speech perception. Secondly, in the absence of clear information about which type of training is best suited to a particular situation, it may be best to incorporate all of them into an auditory training program. Although an eclectic program does cover both of the above situations, research into the effectiveness of different training approaches for particular classes of clients is required to find the most efficient combination of strategies.

ISSUES IN AUDITORY TRAINING RESEARCH

Unfortunately, much previous research related to auditory training does not make it possible to evaluate its effectiveness directly. For example, all studies of tactile speech processors require training, but rarely do they compare trained and untrained users or different training strategies. This is understandable because usually their objective has been to improve the design of tactile processors, however, the opportunity to assess training separately from the combined device-plus-training effect has often been missed. Consequently, it is very difficult to evaluate the relative effectiveness of devices because the amount and type of training given to the subjects is usually different (Blamey & Cowan, 1992). Research into hearing aids and cochlear implants involves similar considerations concerning training effects. In these cases, the training effects are usually less obvious if the subjects are postlinguistically deafened adults who achieve a reasonable level of speech recognition with relatively little experience. Even so, substantial learning does take place over time (Dowell, Mecklenburg, & Clark, 1986), and this can be affected by training. It would be feasible and advantageous to design and complete studies that would address some of the issues discussed below.

Effectiveness of Training

The three main issues involved in establishing the effectiveness of training are: (a) how to evaluate an improvement, (b) whether the improvement reflects a significant change in the listener's perception of the real world, and (c) how long the effects of training are retained.

Assessment. An auditory training program should start with a comprehensive assessment of the auditory skills of the client for two reasons. Firstly, the initial level of performance must be established accurately for comparison with performance during and after training. The initial and final evaluations must include materials that are representative of realistic situations so that reliable inferences about the client's performance outside the test situation can be made. Secondly, the assessment must identify specific areas of weakness in the client's performance so that the training can concentrate on these areas to achieve the maximum improvement. Usually, this will require testing of closed-set materials or structured open-set materials such as monosyllabic words (Boothroyd, 1968), or the SPIN sentences (Kalikow, Stevens, & Elliot, 1977). During training, progress is monitored by shorter assessments that need to be related closely to the training materials, and may form part of the practice provided to the client. These measures ensure that the training tasks remain appropriate and help to maintain motivation. Ongoing assessments also provide valuable information if the rate of progress is not uniform. If learning occurs rapidly at first and then slows down, it may be more cost-effective to halt training before a plateau in performance is reached. Learning sometimes progresses in a series of jumps rather than smoothly. In this case, the jumps may indicate that several processes are being learned together and specific training of these individual processes might produce the jumps in performance more quickly. For example, Alcántara, Whitford, Blamey, Cowan, & Clark (1990) reported step-like changes in recognition of speech features among children who received specific training with an electrotactile speech processing device combined with hearing aids.

Generalization. It is essential to demonstrate that auditory training will improve communication in real-life situations as well as under artificial test conditions. This involves a wide variety of evaluation materials, speakers different from the person(s) who carried out the training, and testing under conditions likely to be encountered outside the clinic or laboratory. Often, improvements in auditory skills are demonstrated in controlled conditions such as those usually encountered during training sessions. Only rarely has it been demonstrated that these changes may be accompanied by improvements under more realistic conditions (e.g., Walden, Erdman, Montgomery, Schwartz, & Prosek, 1981). There is little information about the factors that determine whether skills learned under one set of conditions will carry over to another set of conditions. Probably, this will depend on the similarity of the tasks and the establishment of a link between them, although the human brain is very good at recognizing patterns or rules and applying them to new situations. Much research remains to be carried out into the factors that promote generalization of skills. Knowledge of these factors will be important in choosing effective training conditions and strategies. Closely related to generalization is the question of how to select appropriate training programs, materials, and goals to meet the everyday needs of individual clients. Some possible approaches were discussed in the section on aims of auditory training, but these procedures would all benefit from further research in order to enhance their diagnostic and prognostic powers. Self-report scales and questionnaires might also be administered pre- and post-training to indicate possible generalization effects of training.

Retention. When new skills are learned under special training conditions, there is no guarantee that they will be retained. If new skills are used regularly in everyday conversation, it is likely that they will be maintained or improved, but if training is discontinued and generalization does not occur, the skills are likely to be lost. Degradation of speech perception skills in adults with postlinguistic hearing loss occurs relatively slowly (Blamey et al., 1992), but these skills have been over-learned and practiced for many years. Presumably, some of the same skills continue to be practiced after the onset of deafness through the mechanisms of speechreading, speech production, reading, and so on. Skills learned through training may not be as well established and may be forgotten more rapidly. Few studies have investigated whether the effects of auditory training persist beyond the end of the training program. Rubinstein and Boothroyd (1987) found that gains made as a result of auditory training were not lost in the month immediately following the end of training.

Comparison of Training Methods

Comparisons of training schemes should take into account the learning rate, as well as the overall improvements in performance. If two training methods achieve the same result but one takes longer, it must be judged that one method is less efficient than the other. The most common method of assessing training schemes is to train with each scheme for a fixed amount of time and measure the improvement. This is not completely straightforward, however. For example, the improvement measured will depend on the client's initial level of skill and the rate of improvement may slow down during training. The improvement will depend on the skill that is evaluated as well as the training method. For example, an analytic method may be more effective than a synthetic method for training recognition of consonants in nonsense syllables. On the other hand, the synthetic method may produce a larger increase in sentence recognition. Thus, comparisons of training methods must be made on the basis of consistent evaluation materials. Some training methods do not lend themselves to this kind of comparison conveniently. For example, the word-learning procedure used by Brooks and Frost (1983) involved training a subset of words until a criterion level was achieved before moving on to another subset of words. A method like this can produce steps in performance, with faster increases for new materials and slower increases as the criterion is approached, particularly if the criteria are difficult to reach. In research using step-wise training methods, it may be advisable to incorporate many steps in order to average out the uneven learning rate.

Cost-Effectiveness

In clinical contexts, training costs are important as well as effectiveness. Costs can be reduced by using group training, trainers with a minimum level of qualification, automated or self-training methods, or longer training sessions less frequently. These variations may influence the effectiveness of the training as well as its cost. Usually, the cost is spread uniformly, but the learning rate reduces over time. Thus, cost-effectiveness decreases as a function of time. Inevitably there comes a cut-off time beyond which training is no longer worthwhile. More effective training leads to higher levels of auditory performance in the same amount of time. Determination of the cut-off time will depend on factors that are not directly related to the training. Such factors include the amount the client or the clinic wish to spend and the social costs of not providing training. Cost-effectiveness also depends on the retention of skills. It should not be assumed that skills trained beyond the level maintained during everyday conversation will persist indefinitely.

Modality of Training

Some proponents of auditory training insist that the auditory signal should be used without lipreading. Others feel that the visual signal does not detract from the training effect of the auditory signal so both should be used together, particularly if the client normally relies on lipreading as well as audition. This question has given rise to widely differing philosophies in the education of deaf children, ranging from auditory/verbal approaches that rely entirely on audition, to the use of specially formulated visual supplements as in cued speech (Cornett, 1967). Many approaches have helped children overcome the problems of hearing-impairment, but no clear indication of the best combination of modalities for training has emerged. This question is also relevant to the auditory training of adults with postlinguistic hearing loss. In the case of adults who are capable of some communication without lipreading, as in telephone use, some training without lipreading seems advisable.

METHODOLOGY FOR AUDITORY TRAINING RESEARCH

The history of auditory training indicates a useful role in at least some cases of adult rehabilitation, but there have been few direct evaluations of its effectiveness. One reason for the lack of objective research in all types of training is the inherent difficulty in obtaining reliable data. Another reason is the large number of factors that influence effectiveness. Methods of overcoming these difficulties in auditory training research are discussed below.

Mathematical Model

The amount of training, the amount of learning, the degree of generalization, and the degree of retention of skills are inter-related. A mathematical formulation is helpful in crystallizing these relationships and testing hypotheses. Equation 1 is an example of a linear differential equation having many of the qualitative properties discussed above:

$$(\mathbf{d/dt})\mathbf{S_i} = (\Sigma_j \mathbf{g_{ij} P_j}) - \mathbf{f S_i} \quad (1)$$

where $(\mathbf{d/dt})\mathbf{S_i}$ is the rate of change (derivative with respect to time) of an auditory skill, $\mathbf{S_i}$, and different subscripts denote different auditory skills such as the recognition of words in sentences or identification of voicing in initial consonants.

$\mathbf{P_j}$ is the amount of practice per unit time on an auditory task denoted by the subscript $_j$, such as 6 hr of general conversation per day, or 1 hr of vowel identification training per week.

$\mathbf{g_{ij}}$ describes the learning effect of practice $\mathbf{P_j}$ on auditory skill $\mathbf{S_i}$.

f describes the rate at which skills decrease in the absence of practice (forgetting rate).

Σ_j denotes a sum over all types of practice (all values of **j**).

The equation states that the rate at which the skill increases is equal to the sum of the effectiveness of each type of practice minus the rate at which the skill is lost without practice. Several aspects of this model should be noted: Firstly, the model can describe explicitly the effects of untrained learning by including the client's everyday experience as one of the types of practice. This would be necessary in the case of a young child, for example. However, in the case of an adult with stable untrained performance, the effect of everyday experience will be the same as the everyday forgetting rate, so both these terms could be omitted. Secondly, the $\mathbf{g_{ij}}$ coefficients provide a measure of generalization by specifying the effect of any given type of practice ($\mathbf{P_j}$) on any given type of skill ($\mathbf{S_i}$). For example, if generalization from practice $\mathbf{P_j}$ to skill $\mathbf{S_i}$ does not occur, this means that $\mathbf{g_{ij}}$ is 0. Thirdly, it is assumed that the probability that a unit of skill will be lost is constant over time so that the forgetting rate, $\mathbf{fS_i}$, is proportional to the level of that skill. Often, $\mathbf{fS_i}$ is quite small (e.g., 0.5% per year in the study of Blamey et al., 1992) and may be ignored in short-term experiments.

Assuming that $\mathbf{g_{ij}}$, $\mathbf{P_j}$, and **f** are all independent of time, integration of Equation 1 gives the skill $\mathbf{S_i}$ as a function of time, **t**:

$$\mathbf{S_i = (1 - e^{-f(t - T)})\,(\Sigma_j g_{ij} P_j)/f} \qquad (2)$$

where **T** is a constant representing the time at which $\mathbf{S_i}$ was 0.

This equation represents a curve that rises with decreasing slope until an asymptote is reached at $\mathbf{S_i = (\Sigma_j g_{ij} P_j)/f}$. Equations 1 and 2 are formulations of a "linear" model that has been used extensively in mathematical learning theory following the work of Hull (1943) and others. The situations studied included discrimination learning, free verbal recall, rote serial learning, imitation learning in children, learning of miniature logic systems by children, aspects of second language acquisition, optimum teaching procedures, and many others. The most detailed studies were carried out over short time spans and usually replaced the time variable with the number of experimental trials of the skill to be learned. Atkinson, Bower, and Crothers (1965) discuss the history and theoretical basis of learning models as well as a number of examples, including experimental data.

The model provides an empirical description of observations in clinical situations and training studies. No theoretical justification will be put forward here, other than that the model is sufficiently flexible to fit many situations. Probably the most serious difficulty in applying the model is in defining the "level of skill." To a first approximation, "level of skill" may be a score on an appropriate speech perception test, but this leads to a problem once the score reaches 100%. The model imposes no upper limit on the level of skill and so will not provide good predictions for tests where performance is close to 100%. A related difficulty is that the level of skill and the score on a speech test need not be linearly related. For example, an increase from 10% to 20% may not represent the same amount of learning as an increase from 20% to 30%. To minimize such problems, the speech tests used to quantify the levels of skill should be chosen to vary over a range that does not lie close to the limits of 0% and 100%. Alternative approaches might be to use a non-linear transformation between the test score and the skill level, to use a more open-ended measure such as speech tracking rate, or to keep scores within a small range by varying an additional parameter such as signal-to-noise ratio.

Illustration of the Mathematical Model

To provide examples, we have applied the model to the clinical data displayed in Figure 1. In each panel of the figure, speech tracking rate, in words per minute (wpm), is displayed as a function of the number of training sessions. Client A was a postlinguistically deafened adult cochlear implant recipient who had used the implant for over 3 years before the data collection began. She was trained for 20 sessions spread fairly irregularly over 49 months. In the first two sessions, the measured tracking rate using the implant without lipreading, $\mathbf{S_I}$, was about 18 wpm. We will assume that the client's performance was stable before training was introduced so that

$$\mathbf{(d/dt)S_I = g_{I0}P_0 - fS_I = 0} \tag{3}$$

or $\mathbf{S_I = (g_{I0}P_0)/f = 18\ wpm}$

where $\mathbf{P_0}$ represents the amount of practice per unit time arising from everyday experience.

$\mathbf{g_{I0}}$ represents the effectiveness of everyday experience on the speech tracking task using the implant without lipreading.

After training is introduced,

$$\mathbf{(d/dt)S_I = g_{I0}P_0 + g_{II}P_I - fS_I} \tag{4}$$

where $\mathbf{P_I}$ is the amount of training per unit time with the implant.

$\mathbf{g_{II}}$ represents the effectiveness of this training on the speech tracking task.

The solid line in Figure 1 represents the integral of Equation 4 that best fits the data. This was determined by adjusting the values of the constants **f**, **T**, and $(\Sigma_j \mathbf{g}_{ij} \mathbf{P}_j)/\mathbf{f}$ in Equation 2 to minimize the sum of squared differences between the data and the fitted values. The values of these constants give us the asymptotic skill level of 48 wpm, and the forgetting rate of 0.11 per month or 0.26 per session. Using Equation 3 and the value of the asymptote, we can also calculate $\mathbf{g}_{II}$ **= 8.1 wpm/session.**

The data for a client with a congenital profound hearing impairment who was evaluated using lipreading-alone for 53 sessions is also shown in Figure 1. The same individual used an electrotactile speech processor (Cowan, Alcántara, Blamey, & Clark, 1988), a hearing aid, and lipreading together for an additional 36 sessions. These data were not collected concurrently and session 0 in the

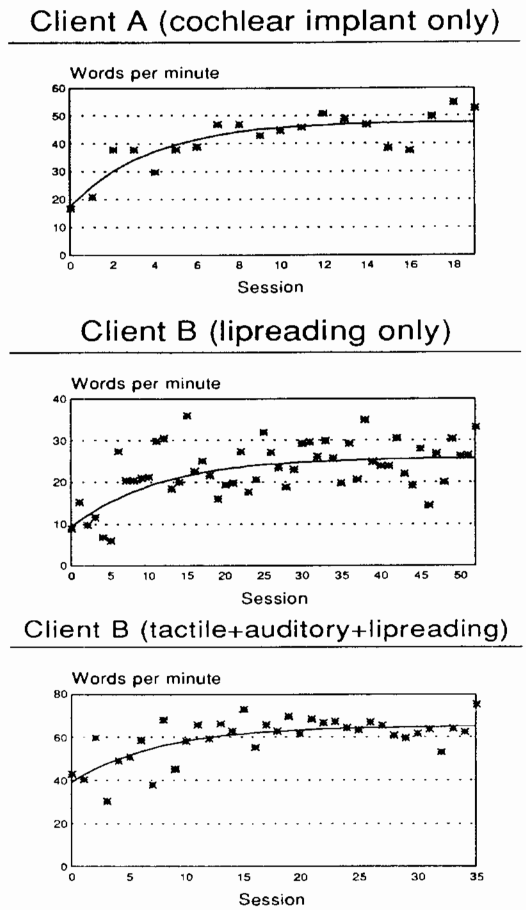

Figure 1. Experimental data and fitted learning curves derived from speech tracking training sessions for two profoundly hearing-impaired adult clients.

combined condition corresponds to session 48 in the lipreading-alone condition. Table 1 summarizes the parameters derived from the mathematical model for each case. The analysis gives us far more insight into the performance of these clients than could have been obtained by considering only the raw data. For example, the effectiveness coefficients indicate that the training was much more effective with the implant than in either of the other two conditions. This possibly reflects the amount of information available in the different training modalities, but it could also be caused by individual differences between the two clients. Although training was most effective with the implant, performance at the point of asymptote was best for client B in the combined condition. This is due to a higher initial performance and to the higher number of training sessions per month. Client B's initial performance in the combined condition reflects the level maintained by everyday experience and includes some contribution from the earlier training with lipreading-alone. These effects could have been separated if the data collection had included an evaluation of the tracking rate in the combined condition at the beginning of the training with lipreading-alone. The forgetting rate in each condition is also of interest. They are all of the same order of magnitude, but much larger than the value inferred from the results of Blamey et al. (1992) which was only 0.004 per month. This suggests that the information or skills learned during speech tracking are forgotten much faster than the skills and information used in the perception of open-set sentences. One possible explanation of this may be that the largest improvements in speech tracking come from familiarity with the context (the story being read) and/or the individual speaker. This detailed information is unlikely to be retained for as long as the general skills required for speech perception which are maintained by everyday use. Thus, we are led to question whether speech tracking had any influence on these more general skills. Unfortunately, the present data do not make it possible to answer this question because an evaluation with test materials other than those specifically trained was not performed. Danz and Binnie (1983) addressed the question in a study with normally-hearing subjects. They found no effect of auditory-visual tracking training on perception of sentences, although there was a small improvement in consonant recognition. Obviously, one cannot draw general conclusions based on data obtained from only two clients. However, modelling may be fruitful in providing a common framework for the interpretation of results from more extensive training studies.

Controls

At first glance, it appears that a training study should involve just an initial evaluation, a training phase, and a final evaluation to see whether any improvement occurred. This approach is not really adequate to demonstrate that the training caused the improvement. For example, naive subjects often perform better on the second exposure to the test conditions and procedures. Training studies are particularly prone to misinterpretation of this kind because the subjects are in a state of change. They may have been recently deafened, or recently

Table 1

Mathematical Model Parameters Derived
From the Speech Tracking Training Data Presented in Figure 1

Client:	**A**	**B**	**B**
Condition	Implant	Lipreading	Lipreading + Hear. aid + Tactile
No. of sessions	20	53	36
Duration (months)	49	18	28
P, sessions per month	0.41	2.94	1.29
Initial level (wpm)	18	9.3	39
Asymptote (wpm)	48	26	65
f, Forgetting rate (per session)	0.26	0.09	0.13
f, Forgetting rate (per month)	0.11	0.25	0.17
g, Effectiveness (wpm per session)	8.1	1.5	3.5

fitted with a new hearing aid and their speech perception skills may be expected to change in response to everyday experience as well as to training. For these reasons, it is prudent to include a "no-training" control group to establish a baseline performance with which the training condition can be compared. If two or more training strategies are being compared and the difference between the strategies is the only variable of interest, a no-training control may be unnecessary. Several studies of this type can be found in the literature. For example, Walden et al. (1981) compared performance for two groups of subjects, one of which received extra consonant training. Rubinstein and Boothroyd (1987) compared the performance of two groups of subjects who received different training in an experimental design that included two no-training phases as well as the training phase. Single-subject designs should also include controls such as a no-training or other-training treatment condition in order to establish a baseline condition. Single-subject designs are more complex than group designs in this respect because the results may depend on the order in which the training conditions are applied.

Evaluation

Because training studies are concerned with the rate of change of skills, they must involve several evaluations separated by intervals of time during which the training or no-training treatments are applied. The initial and final evaluations need to produce highly reliable estimates of performance because the effectiveness of training will be measured by a difference in scores. This requirement is especially important for short-term studies in which the improvement due to training may be small, and for studies where different training strategies are compared with one another. To illustrate the nature of this problem, consider a group experimental design in which the performance of group A who receive training, is compared to the performance of group B who do not receive training. Assume a test that yields a distribution of individual scores with a standard deviation of 10%. Table 2 shows the standard deviations of the distributions of group scores and differences. Note that the distribution of differences between two scores has double the variance of the distribution for a single score. To demonstrate that learning for group A is greater than zero with 95% confidence level, the change in performance must be at least two standard deviations away from zero. In other words, post-training performance must be at least 14% higher than pre-training performance. Similarly, the amount of learning for group A must be 20% higher than for group B to demonstrate a significant training effect. The requirement for such a large training effect can be overcome to some extent by using larger numbers of items in the evaluation in order to reduce the test score variability, by using a larger number of subjects to reduce the variability of group mean improvements, and by training for a period of time that is sufficiently long to produce a large improvement in test scores. All of these conditions involve increased time for the researcher and the clients, making research into training an expensive exercise.

Group Designs

Group designs are useful for several reasons. Firstly, a control group allows for the possibility that subjects' evaluation scores may change in the absence of training. Secondly, other variables may be controlled. For instance, the evaluation materials may have been equated for difficulty in normative studies, but it is prudent to balance the order of presentation across subjects within groups

Table 2

Standard Deviations of Distributions of Scores in the Analysis of a Group Design to Evaluate a Training Effect

Quality Evaluated	Standard Deviation
Individual subject score	10%
Initial group mean score	5%
Final group mean score	5%
Group learning effect (final − initial group score)	7%
Training effect (group A − group B learning effect)	10%

Note. A group size of 4 subjects is assumed. It is assumed that subjects are perfectly matched so that subject variations do not increase the group standard deviations above the level arising from test-retest variation of the evaluation used. In practice, individual differences will increase the standard deviations of group mean scores.

to control for any differences between them. Similarly, groups may be matched to minimize the effects of extraneous variables such as age, degree of hearing loss, or hearing aid used. It is often desirable to evaluate variables explicitly, rather than using a balanced group design. In this case, the groups may be deliberately selected with differences in these factors so that any interactions between the selected variable and the training condition can be observed. Some factors such as hearing loss can only be evaluated in group experiments because they can not be controlled in a single-subject design. Group designs also reduce the possibility that an unrepresentative result will be obtained from a small number of subjects. Larger numbers of subjects help to reduce the variability of mean learning rates and improvements calculated from the data. It should be noted that an equal reduction in variability can sometimes be attained by increasing the number of items in the evaluation test and by repeating the evaluation several times. The latter options are preferable in many situations because the time spent on training is not increased, and training time is usually much greater than the evaluation time.

Single-Subject Designs

A single-subject design does not require matched groups of control and experimental subjects. On the other hand, the single subject must be evaluated in a multiple-phase experiment if improvements are to be attributed to training unambiguously. For instance, an improvement observed in a 1 month period may be due to training, or to other events such as a resolution of personal problems, reduction of a conductive hearing loss, or everyday auditory experience. To eliminate these possibilities, a non-training phase is desirable, as well as the evaluation of variables likely to be affected by uncontrolled factors (such as hearing thresholds). A non-training phase is a time when evaluations are carried out before, after, or in between training phases in order to establish whether performance is stable in the absence of training. A demonstration that auditory speech perception improved during training but not at other times, and that untrained skills did not change simultaneously is much more convincing evidence of the specific effects of training than an uncontrolled study. Order effects can be important. The improvement in the first phase is often greater than in following phases because motivation is high and there is more to learn. In later phases, the client may already have reached a higher level of competence, and learning further skills may be more difficult. Consequently, several interleaved training and non-training phases may be preferred. An alternative that also adds to the generality of results is to combine single-subject and group methodologies with the order of phases balanced across subjects. This design was used by Alcántara, Cowan, Blamey, and Clark (1990).

Factors Influencing Effectiveness

The effectiveness of auditory training depends on extrinsic factors as well as those directly controlled by the clinician. These factors may produce a wide variation of results within groups of clients, and make it more difficult to obtain reliable measures of learning rates. These factors need to be considered in designing research studies. Also, they must be controlled, as much as possible, by selecting homogeneous groups.

Hearing levels. Severe hearing losses restrict the cues available and impose an upper limit on the level of auditory skills that may be learned. In terms of the suggested mathematical model, the $\mathbf{g}_{ij}$ (gain) coefficients will tend to be smaller for greater hearing losses. Coefficients corresponding to skills $\mathbf{S}_i$ that require the greatest auditory sensitivity may be zero, indicating that no amount of training would improve these skills. Other skills that do not require such high levels of auditory sensitivity may be improved. Minor hearing losses may also render training ineffective because a high level of auditory skill is likely to be attained through everyday conversational experience. Training to achieve a level of auditory skill above that maintained by the client's everyday conversational experience will have only a temporary effect, since the skills will gradually decrease to the stable level after training is removed. One example of this could arise from intensive training of a client by a single speaker. If the client learned to use particular characteristics and mannerisms of the speaker that were not generalized, one would expect these skills to be lost relatively quickly after training. Second language acquisition is another good example where skills decrease if unused for long periods of time.

Device used. The total effect of a hearing loss on communication depends on the compensating benefits achievable with a hearing aid or other sensory-prosthetic device, as well as on the negative effect of the hearing loss. One would therefore expect that the effectiveness of training would be greater for more effective sensory-prosthetic devices. Thus, the benefits of a well-fitted sensory-prosthetic device may include faster learning of auditory skills as well as a higher stable level of performance with the device. The first electronic hearing aids were not wearable and were used exclusively in training sessions because learning was faster with the help of the aid. Modern hearing aids and cochlear implants are wearable, however, and offer stable levels of auditory performance that are higher than the level of performance that could be achieved in the unaided condition, as well as faster learning of the required skills. In evaluations of assistive devices, the learning aspect is often dismissed on the tacit assumptions that no new auditory skills will be learned with the new aid, or that the relative levels of performance with alternative aids will not be affected significantly by learning. These assumptions are justifiable in comparisons of similar devices such as hearing aids with small differences in the gain characteristics across frequency. New generations of assistive devices that are quite different from conventional hearing aids are being developed. They include speech-processing hearing aids, cochlear implants, and tactile processors (Levitt, 1986). For these devices, the previous assumptions may no longer be justifiable.

To clarify this statement, consider the hypothetical case of an adult with a severe hearing loss who uses a hearing aid, and later decides to get a cochlear implant. We will apply the mathematical model hypothetically to explore the possible outcomes for the client (see Figure 2). Let $\mathbf{S_h}$ be the level of skill with the hearing aid and $\mathbf{S_c}$ the level of skill with the implant. Immediately prior to the implantation, $\mathbf{S_h = g_{hh}P_h/f}$, where $\mathbf{P_h}$ is the practice obtained with the hearing aid under everyday conditions and $\mathbf{g_{hh}}$ is the effectiveness coefficient for everyday hearing aid practice (second subscript) on perception using the hearing aid (first subscript). The example assumes that the hearing aid user has had stable hearing over several years and has reached an asymptotic level of performance with the aid. Similarly, $\mathbf{S_c = g_{ch}P_h/f}$ when the implant is first used. In this case, the relevant effectiveness coefficient, $\mathbf{g_{ch}}$, refers to the effect of everyday hearing aid experience on perception with the cochlear implant (note that $\mathbf{g_{ch}}$ is non-zero because we presume that the client's pre-operative experience with the hearing aid contributes to postoperative performance with the implant). $\mathbf{S_c}$ is shown preoperatively by the dashed line in Figure 2 because it cannot actually be evaluated until after the implant operation. If the implant provides quite different information than the hearing aid, $\mathbf{g_{ch}}$ is likely to be smaller than $\mathbf{g_{hh}}$ and the implant user will perform worse with the implant than with the hearing aid to begin with (as shown in Figure 2). On the other hand, if $\mathbf{g_{ch}}$ is greater than $\mathbf{g_{hh}}$ there will be an immediate improvement in skills when the hearing aid is replaced by the implant. This is possible if the implant provides information in a similar form to that provided by the hearing aid, but with greater precision. Several years later the stable level of performance with the implant will be $\mathbf{S_c = g_{cc}P_c/f}$, where $\mathbf{g_{cc}}$ is the effectiveness coefficient for everyday practice on perception with the implant. This is shown by the asymptotic performance on the right of Figure 2. We will assume that the implant is used for the same amount of time and under the same circumstances as the hearing aid was previously used, so that $\mathbf{P_c = P_h}$. The benefit of the implant depends on the comparison of $\mathbf{g_{cc}}$ with $\mathbf{g_{hh}}$. If the implant provides access to information not available through the hearing aid, $\mathbf{g_{cc}}$ may exceed $\mathbf{g_{hh}}$ and provide a significant benefit even though $\mathbf{g_{ch}}$ may have been less than $\mathbf{g_{hh}}$ and the implantation resulted in an initial drop in performance. As this example illustrates, the effect of learning can be very important in arriving at the best decision regarding the benefits of an assistive device. If training is provided in the initial period after the operation, the long-term level of performance with the implant may be reached more quickly since $\mathbf{(d/dt)S_c = g_{cc}P_c + g_{ct}P_t - fS_c}$, where $\mathbf{g_{ct}}$ is the effectiveness coefficient of the training and $\mathbf{P_t}$ is the practice provided during training. To be beneficial, $\mathbf{g_{ct}}$ must exceed $\mathbf{g_{cc}}$ by a large factor because $\mathbf{P_t}$, the time spent on training, is usually much smaller than $\mathbf{P_c}$, the time spent using the implant in everyday conditions. Figure 2 displays the auditory skills of this hypothetical case as a function of time. The difference between the upper and lower curves after the implantation indicates the cumulative effects of the training. Note that once training ceases, the difference between the two curves is gradually reduced as they both tend to the same asymptote, determined by the

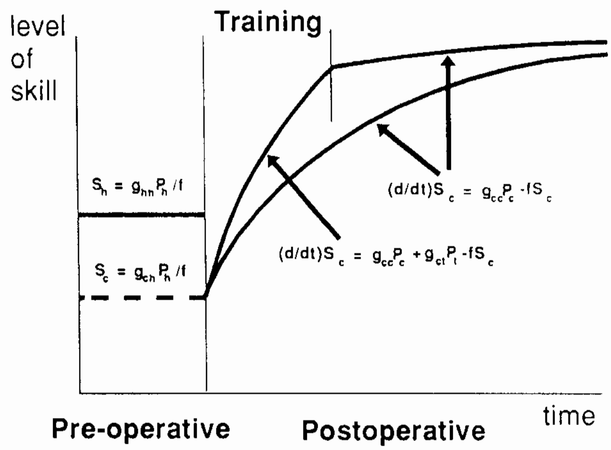

Figure 2. Theoretical learning curves for a hearing aid user who decides to have a cochlear implant. Post-operatively, two learning curves indicate predicted performance with and without a short period of training. See the text for a full explanation.

client's everyday experience with the implant.

The post-operative performance described by the upper learning curve in Figure 2 is analogous to that of a sub-group of five cochlear implant users who received an eclectic auditory training program shortly after implantation (Lansing & Davis, 1988). Their performance improved on several auditory perception tasks during the rehabilitation period, and performance was maintained at the improved level for a further 9 months without training. In the same study, a control group of eight implant users showed evidence of untrained learning for vowel and consonant perception (as would be suggested by the lower learning curve in Figure 2). The control group received training 9 months after implantation and then improved to about the same level of performance as the experimental group. The authors do not give pre-operative hearing aid scores on the same tests, so it is not possible to determine whether there was an initial drop in performance as postulated in Figure 2. Nor is it possible to estimate the $\mathbf{g_{hh}}$ and $\mathbf{g_{ch}}$ coefficients for these subjects.

Auditory experience. As illustrated by the hypothetical example above, the difference between trained and untrained performance is transitory and the long-term stable level of an auditory skill is determined by the amount of practice under everyday conditions. Thus, training becomes less worthwhile for a client who already has a lot of auditory experience and is approaching the projected stable level of performance. A person who is well below the stable level of performance has more to gain, and will learn faster than someone who is already close to the stable level. Thus, training tends to be more useful at times when conditions have changed through a sudden loss of hearing, or the fitting of a new device because these changes alter both the immediate performance level and the projected stable level. A notable exception to these statements may be the case where the training itself has an effect on the everyday experience of the client. For example, the training may introduce the client to a new group of acquaintances or increase confidence and motivation so that the amount of everyday interaction is significantly increased even after training ends. Pragmatic training can also increase the effectiveness as well as the amount of everyday auditory experience.

Environment. The environment determines the hearing conditions under which the client must operate in everyday life, and training should aim to increase performance under these conditions. Given that one may wish to produce the maximum improvement under particular conditions, what implications does this have for the selection of a training method? This question is equivalent to the problem of finding the type of practice $\mathbf{P}_j$ for a given auditory skill $\mathbf{S}_i$ such that $\mathbf{g}_{ij}$ is maximized. One might expect that training should be given under the conditions in which communication will often occur, for example, training in noise may be most appropriate for people who work in noisy environments. There are reasons why this may not be the best strategy, however. The first reason is that learning often progresses from simple to more complex stages. In analogy with arithmetic teaching, the initial stages of learning may occur more quickly under simplified and/or formalized conditions. One might also wish to use artificially difficult conditions to concentrate attention on particular aspects of the task, or to challenge the client to reach a higher level of performance. It is possible that a variety of conditions including both artificially simplified and artificially difficult tasks may be more effective than matching real conditions. This is in contrast to the requirements of evaluation which should be administered under conditions that resemble real-life situations, subject to the usual requirements of reliability and sensitivity of the test.

Personality. Individual differences between clients can be influenced by factors more subtle than those discussed so far. Research into the effects of client and clinician personalities on the effectiveness of training is complicated by a lack of quantitative measures and the multivariate descriptions required to characterize human attitudes and styles of interaction. Motivation, willingness to learn, willingness to accept criticism and act on it, adaptability, and intelligence are all characteristics that may influence the rate of learning and the eventual effect of training on everyday speech perception skills. For example, Bode and Oyer (1970) suggested that age and intelligence had significant effects on the learning rates within their groups of adult subjects. Many personality characteristics are difficult to quantify but their effects can be significant, nevertheless. Some of these are attitudes that can be changed or controlled rather than fixed characteristics, and the training strategy should be designed to encourage positive attitudes (Binnie, 1977). For example, it is necessary to provide opportunities for success early in training to increase enthusiasm and confidence. Without early success, many clients will give up trying. Too much success can also have negative effects, leading to overconfidence or boredom. We learn from our mistakes, but too many or too few mistakes can reduce the learning rate. Criterion-based training strategies where progress is contingent on reaching short-term goals, go some way towards achieving a compromise. It may still be necessary, however, to recognize the differences between individuals by choosing criteria appropriately to maintain motivation and avoid stagnation. These considerations are largely dependent on the skill of the trainers and their sensitivity to the attitudes and progress of the clients. Training schemes should therefore be designed to allow choice of materials, rates of progress, and interaction styles that are well suited to the personal traits of the client.

THREE STUDIES OF ANALYTIC AND SYNTHETIC TRAINING

In this final section, we will briefly discuss three studies concerned with the effects of analytic and synthetic training on speech perception (Alcántara, Cowan, Blamey, & Clark, 1990; Rubinstein & Boothroyd, 1987; Walden et al., 1981). These three studies are of interest because they illustrate the diversity of effects that can arise from training studies under different experimental conditions.

In an auditory training study (Rubinstein & Boothroyd, 1987), 10 subjects received 8 hr of synthetic training on sentence perception and 10 subjects received 4 hr of synthetic training and 4 hr of analytic consonant recognition training. The CUNY Nonsense Syllable Test and the Revised Speech Perception in Noise Test (RSPIN) were used for evaluation. A significant post-training improvement was found for the high predictability items of the RSPIN test, but there was no significant improvement on low predictability items or on the nonsense syllables. The study incorporated no-training phases before and after the training phase, and demonstrated that the improvement in perception of high predictability sentences occurred during the training phase. There was no significant difference between the groups trained with the different methods.

In an earlier study (Walden et al., 1981), a standard 50-hr aural rehabilitation program was provided to three groups of hearing-impaired adults. Ten adults received an extra 7 hr of auditory consonant recognition training, 10 adults received an extra 7 hr of visual consonant training, and the third group of 15 adults received no extra training. The subjects who did not receive the extra analytic training did not improve on consonant recognition. All three groups improved on audio-visual sentence recognition, but the two groups receiving extra training improved significantly more than the other (control) group.

The third study (Alcántara, Cowan, Blamey, & Clark, 1990) was carried out with seven normally-hearing subjects in two groups using a multi-channel electrotactile speech processor and lipreading. One group received synthetic (S) training for 35 hr followed by 35 hr of combined analytic and synthetic (AS) training. The other group was trained in the two conditions in the opposite order. Evaluations were carried out before training, at the mid-point, and at

Table 3

Mean Improvements for Seven Subjects Using the Analytic-Plus-Synthetic (AS) and Synthetic (S) Training Strategies in the Tactile-Plus-Lipreading (TL), Tactile (T), and Lipreading (L) Conditions

Test	Condition	Training Strategy AS	Training Strategy S
Vowels	TL	17*	26*
	T	52**	7
	L	13	20*
Consonants	TL	40**	17
	T	30**	6
	L	24**	9
CNC Words	TL	6	11**
	L	3	4*
CID Sentences	TL	15**	17**
	L	6	14**
Speech Tracking	TL	16*	30**
	L	9*	20**

Note. Vowel, consonant, CNC Word, and CID Sentence score improvements are shown in percent correct. Improvements in speech tracking are in words per minute.

*indicates an improvement significantly greater than zero with $p < .05$. **indicates the significance level is $p < .01$ using the Wilcoxon Matched Pair Signed Rank Test.

the end of training. The replicated within-subject design allowed each subject to act as their own control, gave each subject access to both training types, and balanced for order effects across groups. Table 3 shows the improvements observed averaged over the seven subjects. Both strategies produced significant improvements with a greater number of statistically significant improvements on the vowel and consonant tests arising during AS training, and a greater number of significant improvements on CNC Words, CID Sentences, and speech tracking during the S training strategy. Only vowels and consonants in the T condition showed a significant difference between the two training strategies ($p < .05$, Wilcoxon Signed Rank Test).

These three studies illustrate several points that have been made in this chapter. Firstly, improvements in some of the speech tests were found for both training strategies, but the patterns of improvements were different. This shows the necessity for effectiveness coefficients that depend on both the type of practice and the skill that is being evaluated. Secondly, the difficulty in demonstrating significant differences between training strategies is shown despite a considerable investment of time in training and the achievement of significant improvements on most tests. Thirdly, the three studies appear contradictory, but these differences may be reconciled if the details of the subjects are considered. Rubinstein and Boothroyd (1987) found no significant effect of analytic training on nonsense syllable recognition, but both of the other studies did. This may have been a result of Rubinstein and Boothroyd's subjects being hearing aid users with relatively high mean aided speech recognition scores. The subjects in the study of Walden et al. (1981) were inexperienced hearing aid users with recently diagnosed hearing losses, and the subjects in the study of Alcántara, Cowan, Blamey, and Clark (1990) had not used the tactile processor before. Walden et al. found that extra analytic training improved performance on audio-visual sentence recognition, but neither of the other studies found a significant difference between synthetic training and a combination of analytic and synthetic training for sentence recognition. The critical difference among the studies may be that the analytic training was additional training in the case of Walden et al., whereas the analytic training replaced part of the synthetic training in the other two studies. These explanations of the different results can only be conjecture, and there is clearly a need for further research to determine more precisely the circumstances under which analytic training is most useful. All three studies suggested that synthetic training had a positive effect on the perception of sentences.

SUMMARY

Speech perception and communication are complex processes, affected by a multitude of factors. One factor is experience, and it is widely recognized that speech perception and communication can improve over time as a result of learning, like many other human activities. Auditory training provides experience that may be beneficial in increasing the information obtained by a person from their hearing. The mathematical model described above can be used to form and test hypotheses about the effects of training and other auditory experience on spoken communication skills. Other factors include the severity of the hearing loss, the hearing aid used, the environment, personal qualities of the client and clinician, the type of training, and the type of evaluation used. Despite a long history of clinical practice, the effects of these factors have been investigated in very few controlled studies. In special cases where the previous experience is severely limited, such as deaf children or adults using cochlear implants and tactile devices, training has an obvious role, but there has been little objective comparison of alternative training methods. One of the main reasons is the difficulty of carrying out definitive experiments that measure changes in performance over time in the presence of many confounding variables. The role of these variables may explain the apparently contradictory results that have been reported in the literature on auditory training for hearing aid users and the diverse points of view expressed by practicing clinicians. These controversies may be addressed rationally through careful research, or they may be resolved by default through social and economic pressures. If you were a person with impaired hearing, which would you prefer?

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