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### Key Words

Aural rehabilitation  
Auditory training  
Auditory plasticity  
Speech in noise

### Abbreviations

LACE: Listening and  
communication enhancement  
HINT: Hearing in noise test  
CSOA: Communication scale for  
older adults  
SB: Speech in babble  
CS: Competing speaker  
TC: Time compressed speech  
TW: Target word  
MW: Missing word  
HHIE: Hearing handicap inventory  
for the elderly

## Variables predicting outcomes on listening and communication enhancement (LACE™) training

### Resultados variables de predicción en el entrenamiento para mejorar la audición y la comunicación (LACE™)

#### Abstract

Results from a large study of adults who completed a randomized crossover study of listening and communication enhancement (LACE™) training were analysed to observe trends. The objective of this study was to determine predictors for greatest improvement following this four-week adaptive auditory training and aural rehabilitation program. Subjects with the poorest scores on the baseline tests, particularly those with the greatest degree of hearing loss, poorest scores on measures of degraded and competing speech, and those with the highest hearing handicap scores, were more likely to have greater improvement overall. However, there was considerable variability among the subjects, and some subjects' positive subjective reports belie smaller overall measured gains. Information collected from both the testing and the counseling of the patient should be taken into consideration when determining whether to proceed with LACE™ training.

#### Sumario

Se analizaron los resultados de un amplio estudio en adultos que completaron un estudio cruzado de distribución aleatoria de entrenamiento para mejorar la audición y la comunicación (LACE™), para observar las tendencias. Los objetivos de este estudio fueron determinar los elementos de predicción para la máxima mejoría después de este programa de entrenamiento auditivo ajustable y de rehabilitación auditiva de cuatro semanas. Los sujetos con las puntuaciones más bajas en las pruebas basales, particularmente aquellos con los grados de hipoacusia mayores, los de puntuación más baja en mediciones con lenguaje degradado y en competencia, y aquellos con la puntuación más alta de impedimento auditivo, eran los que tenía mayores posibilidades de mejoría global. Sin embargo, existió una considerable variabilidad entre los sujetos, y algunos reportes subjetivos positivos ocultaron ganancias medidas globales más pequeñas. La información colectada tanto de la evaluación como de la orientación del paciente, debe ser tomada en consideración en el momento de determinar cuando proceder con un entrenamiento LACE™.

One of the most frequent complaints of hearing-impaired patients is the inability to understand speech in noise. It is well documented that sensorineural impaired listeners have greater difficulty in adverse listening conditions than their normal-hearing peers (Olsen & Tillman, 1968; Olsen et al 1975). Often, individuals with hearing loss report adequate hearing in quiet environments and for slowly presented speech, but greater difficulty in noisy situations and when speech is at a rapid rate. Often these difficulties are greater than can be explained on the basis of audibility alone, (Pavlovic, 1984; Smoorenburg, 1992). This may be due, in part, to the loss of non-linearity and the consequent reduction in tuning due to broadened filters of the auditory system (Moore, 2002). However, problems understanding speech in adverse acoustic conditions are not only limited to peripheral damage. For example, auditory deprivation and peripheral attenuation, as well as the introduction of novel stimuli, leads to altered cortical representation (Robertson & Irvine, 1989; Klinke et al, 1999). The impact, if any, of this reorganization on one's ability to understand speech and process complex signals is not fully understood (Irvine et al, 2000). Other central functions also play a role for hearing-impaired listeners. The effects of normal aging on cognitive skills such as

speed of processing, working memory, and executive control create additional detrimental effects on speech understanding in difficult listening situations (Pichora-Fuller & Singh, 2006). This is relevant considering the fact that the average age of new hearing aid users is over 65 years old (Kochkin, 2005) and that in adverse conditions, audibility is only partially restored with hearing aids. In fact, elderly subjects with hearing within normal limits perform similar to younger hearing-impaired subjects on difficult listening tasks (Gordon-Salant & Fitzgibbons, 1999). In addition, most hearing-impaired adults delay obtaining professional services for several years after first recognizing that a hearing loss is present (Sweetow & Sabes, unpublished data). This period of time is more than sufficient to develop maladaptive compensatory listening habits.

Given the combination of these peripheral, central, and behavioral influences, it is unrealistic to expect that individuals, particularly the elderly population, would be able to instantly and optimally synthesize the novel and partial auditory cues provided by new hearing aids without experience or training. Indeed, one would not expect an amputee to be furnished with a new prosthetic device without the benefit of some type of physical therapy intervention, yet this is precisely what is done for most people

receiving new hearing devices. Conveying information, not only about the hearing loss and use of hearing aids, but also about rehabilitation and communication repair strategies, can allow individuals to better manage their environment and daily activities (Andersson et al, 1997). Due to constraints on the clinician's time, however, in-depth counseling sessions are not always possible.

Furthermore, patients presenting similar audiometric profiles frequently obtain diverse benefit from amplification. One reason is related to an individual's ability to attentively blend a minimum of acoustic, linguistic, and external environmental cues together to form a cogent message. To truly benefit from hearing aids, one must assimilate hearing with listening, comprehension and successful communication strategies. There is a fundamental difference between hearing and listening. A person can possess normal hearing, yet be a very poor listener. Conversely, a good listener requires the ability to hear, but not necessarily normally. Hearing is a sense. Listening is a skill. Hearing requires audibility. Hearing requires access to acoustic information. To be a good listener, however, one must integrate a number of additional skills. Meaningful listening requires hearing (access to acoustic cues), but in addition, it requires intension, attention, understanding, and remembering.

Modern hearing aids can provide audibility, but may not rectify impaired frequency and temporal resolution. As a result, most hearing aid users must operate with a set of incoming signals that is different, and presumably inferior, to that of individuals with normal hearing. In other words, the hearing aid user generally receives a fragmented or partially degraded signal, either because of extrinsic sources such as noise interference or limited bandwidth, or from underlying intrinsic limitations such as imperfect audibility, cochlear distortion, impaired frequency and temporal resolution, and reduced cognitive function. In addition, as stated earlier, hearing-impaired listeners also may develop compensatory tactics that may be maladaptive to their optimal listening skills, such as 'tuning out', or dominating the conversation. Recent discoveries in the field of neuroscience suggest that auditory skills might be enhanced with training (Tremblay, 2001; Fu et al, 2005; Amitay et al, 2005). An evidence-based review of individualized auditory training indicates significant benefit from such programs (Sweetow & Palmer, 2006). In addition, a number of studies have demonstrated benefits obtained from informational counseling and listening training from either individual or group presentations (Kramer et al, 2005; Wayner, 2005; Kricos & Holmes, 1996). Despite this evidence, there have been obvious deficiencies in at least two areas. One is the availability of cost-effective and plausible therapy programs for hearing-impaired adults, and the other is the identification and understanding of variables that predict and affect outcomes of such intervention.

Based on these concepts, coupled with the wide, often unpredictable, range of success with amplification despite apparent homogeneity in hearing thresholds, a new program, LACE™ (Listening and Communication Enhancement) was created (Sweetow & Henderson Sabes, 2006). LACE™ is an interactive computerized training program designed for home use. Similar to the concept by which physical therapy can help rebuild muscles and adjust movements to compensate for physical weakness or injury, the purpose of LACE™ is to improve listening, communication skills, and provide strategies that can help compensate in those situations when hearing is

inadequate. LACE™ provides a variety of interactive and adaptive tasks that are divided into three main categories: degraded speech, cognitive skills, and communication strategies. A full description of the development and validation of LACE™ training is available (Sweetow & Henderson Sabes, 2006). A brief description of the training exercises in LACE™ follows.

#### *Degraded speech*

For the degraded speech exercises, speech is either presented in background babble noise (SB) or with a single competing speaker (CS) (male, female, or child), or is time-compressed (TC) to simulate a person who speaks rapidly. The trainee listens to and identifies the 5–8 word sentence or phrase, then views the correct response on the screen. If the message is identified as being correctly interpreted, the next sentence or phrase is presented at a slightly more difficult level (reduced signal to noise ratio or greater time compression); if the message is misinterpreted, the next sentence is presented at an easier level. In other words, the difficulty level of the task is based on the accuracy of the patient's response to the previous task. These tasks are situations in which hearing-impaired patients often have difficulty. Allowing patients to practice with feedback, in a comfortable environment was a main focus of this training program.

#### *Cognitive skills*

The system provides training exercises designed to enhance auditory memory and speed of processing—two elements of listening that are particularly important in noisy environments. These exercises take the form of a missing word in a sentence or phrase that is 'filled in' by the patient (MW), or asks the trainee about words preceding or following a 'target word' in the sentence (TW). The purpose is to remind patients that linguistic and contextual knowledge can be utilized to complete identification even when acoustic components of the signal are missing.

#### *Communication strategies*

LACE™ also presents strategies that help people cope with their daily communication activities. These 'hints' include tips on a wide variety of strategies such as procuring hearing-conductive seating in a noisy restaurant, advice on telephone use, and communication tips for patients and their friends and loved ones. The purpose of this portion of the training was to provide information to the patient over time, rather than a single booklet or counseling session, which can be overwhelming.

It was not the goal of the software to train global cognition, but rather skills that directly impact speech perception. For example, speech is a temporal sense and occurs at rates of 4–5 syllables per second. A decrease in speed of processing could create a deleterious effect on speech perception, particularly in difficult listening environments. Similarly, auditory memory, particularly working memory, occurring on the time-scale of seconds to minutes, is crucial for individuals to effectively 'fill in the gaps' created by their loss of audibility. Cognitive processing speed and auditory memory have been shown to be improved with training (Ball et al, 2006) in recent studies.

Trainees are asked to participate for 30 minutes per day, 5 days per week, for 4 weeks (10 hours total). Orthographic feedback is provided to the patient immediately following each stimulus

presentation. At the completion of each 30 minute training session, a graph is presented illustrating progress from the beginning of training. This is intended to motivate patients by letting them see their progress, and to improve their confidence. It also reasserts the value of their choice to obtain amplification (in the case of a hearing aid purchase) and hearing care rehabilitation.

The results of the training are tracked by the software, and the data can be electronically transmitted to a secure website ensuring confidentiality. These data are accessible by the audiologist with the permission of the patient. In this way, the patient's progress can be monitored, and individualized recommendations can be made as he/she progresses through the program.

In a multi-site study of the effectiveness of LACE™ on 65 subjects, significant improvements were found not only on the training tasks, but also on a variety of standardized outcome measures including the QuickSIN (Killion et al, 2004; Etymotic Research, 2001), hearing in noise test (HINT) (V. 6.3 Maico Diagnostics; Nillson et al, 1994), hearing handicap inventory for elderly (HHIE), (Ventry & Weinstein, 1982), and communication scale for older adults (CSOA) (Kaplan et al, 1997) (Sweetow & Henderson Sabes, op cit). A summary of these changes is shown in Tables 1 and 2.

However, as stated earlier, questions remain regarding how to identify individuals who might benefit from training and what variables are most closely associated with prognosis from this type of aural rehabilitation. For example, how do age, hearing loss, and baseline handicap assessment impact outcomes? As part of the investigation of the overall effectiveness of LACE™, a correlation analysis was performed to ascertain some of these answers.

## Methods

### Subject population

Sixty-five subjects participated in the investigation. A study with a between group, within-subject, experimental design with pre- and post-test measures was conducted at five clinical sites across the United States. IRB approval was obtained through the University of California. Subjects ranging in age from 28–92 were randomly placed into one of two groups (mean = 64.7 years, SD = 14.9 years). Group 1 (n = 38) subjects started the training immediately after the initial testing session. Group 2 (n = 27) subjects completed the initial test session, returned one month later to complete a second test session (end of control period), and then started training (crossover period). The

**Table 2.** Mean scores of all trained subjects prior to training (baseline) and at the end of training (post-training). All post-test scores except the HINT are significantly improved from the baseline measurement (repeated measures ANOVA,  $p < 0.05$ ). Redrawn from Sweetow & Henderson Sabes (2006).

Task	Baseline	Post-Training	
QuickSIN @ 45 dB	9.20	7.00	dB SNR loss
QuickSIN @ 70 dB	6.50	5.00	dB SNR loss
HINT	3.20	2.30	dB SNR
HHIE	35.10	27.60	Handicap score
CSOA-S	3.00	2.84	Raw score
CSOA-A	2.44	2.38	Raw score

demographics of the groups have been previously published (Sweetow & Henderson Sabes, 2006). Fifty-six subjects were experienced hearing aid users (6 months to 44 years). Approximately 85% of these subjects wore binaural amplification. The other nine subjects did not use amplification but reported difficulty understanding speech in adverse listening environments, five of these subjects had normal hearing thresholds. New hearing aid users were not included in this study due to possible effects of acclimatization. Subjects completed training on a personal computer using dedicated speakers, or a prototype hardware device.

### Training stimuli

Approximately 2000 sentences were used as stimuli. For speech in babble (SB), time compression (TC), and competing sentences (CS) training tasks, the subject was asked each day to choose a subject topic (e.g. money matters, exercise, health, or potpourri) and was trained using sentences relevant to that topic. Target word (TW) and missing word (MW) training tasks used designated sentences. Samples of the tasks can be seen and heard by downloading a demonstration of LACE™ at <http://info.lacecentral.com/>. Stimuli were presented in the sound field at the subject's most comfortable level (MCL). MCL was assessed at the start of each session. Subjects were instructed to not change the volume settings of their computer, speakers, or hearing aids for the rest of the session. In the SB, TC, and CS training tasks, 60% of the stimuli were presented at MCL, 20% were presented at +5 dB re MCL, and 20% were presented at -5 dB re MCL. The TW and MW training tasks were all presented at MCL.

Two to three training tasks were presented in each 30 minute training session. Subjects were instructed to train when not

**Table 1.** Mean presentation level (threshold) for each training task for each quartile of the training program. Speech in babble and competing speaker task thresholds are measured in dB SNR, time compression is measured in percent compression, auditory memory is measured in difficulty levels (1–6), and missing word in adjusted response time. Asterisks reflect a significant change from the preceding quarter. Redrawn from Sweetow and Henderson Sabes (2006).

Task	Quarter 1	Quarter 2	Quarter 3	Quarter 4	
Speech/Babble	6	4.6*	4	3.2*	dB SNR
Time Compression	58	55*	53*	52	% Comp
Competing Speaker	2.7	1.5*	-0.2*	-1.1	dB SNR
Auditory Memory	3.7	4*	4.1	4.4*	Diff. Level
Missing Word	2.4	2.2	2	1.9*	Adj. RT

fatigued, to maintain a consistent schedule, and to always answer honestly.

### Test measures

Test sessions included objective and subjective test measures. Objective testing was conducted with the aided subjects wearing their hearing aid(s) at the same user setting at which they completed the training exercises. Although electroacoustic monitoring of the hearing aids was not completed at every test session, hearing aids were determined to be in working order through a listening check by a normal hearing clinician. At each test session, all subjects completed two speech in noise tests: three lists of the QuickSIN at 45 dB HL and at 70 dB HL, and the HINT at a 65 dBA noise level (noise at 0 degree azimuth). These tests were included to determine if changes in speech perception were generalized to different stimuli, speakers and background noise. To determine whether changes were observed in subjective reports of handicap, strategies and outlook, subjects also completed the standard version of the hearing handicap for the elderly (HHIE), or the hearing handicap for adults questionnaire (HHIA), (Newman et al, 1990). If the subject was 65 or younger, or engaged in regular employment, the subject completed the HHIA. Subjects also completed the five-point CSOA. The CSOA is comprised of two subscales, a communication strategies subscale and a communication attitudes subscale. It is a measure designed to show changes in attitudes and use of communication strategies in adults. Both the HHIE and the CSOA were administered in paper-and-pencil form.

### Testing schedule

Group 1, the immediately-trained group, had testing completed prior to training (baseline), at 2 weeks into the training (mid-training), at the end of the 4 week training program (post-training), and then at eight weeks (four weeks post-training). Group 2, the crossover subjects, received testing at baseline, and four weeks later, just prior to their start of training. They then received testing at 2 weeks into the training (mid-training), at the end of the 4 week training program (post-training), and at eight weeks (four weeks post training). Using a crossover design allowed subjects in Group 2 to serve as their own controls.

### Results

The purpose of the experiment was to determine the variables associated with prognosis for this aural rehabilitation program. The ensuing discussion first considers correlation of subject characteristics (age and hearing loss), and baseline test performance with each other; the subsequent analysis considers the impact of these variables upon performance improvement. There were no significant differences between the trained subjects in groups 1 and 2, so the training data were pooled for these two groups.

#### Correlation of subject characteristics and baseline test performance

Multiple regression correlative analyses were performed on all of the baseline measures and the results are displayed in a correlation matrix in Figure 1. In this figure, red shaded cells

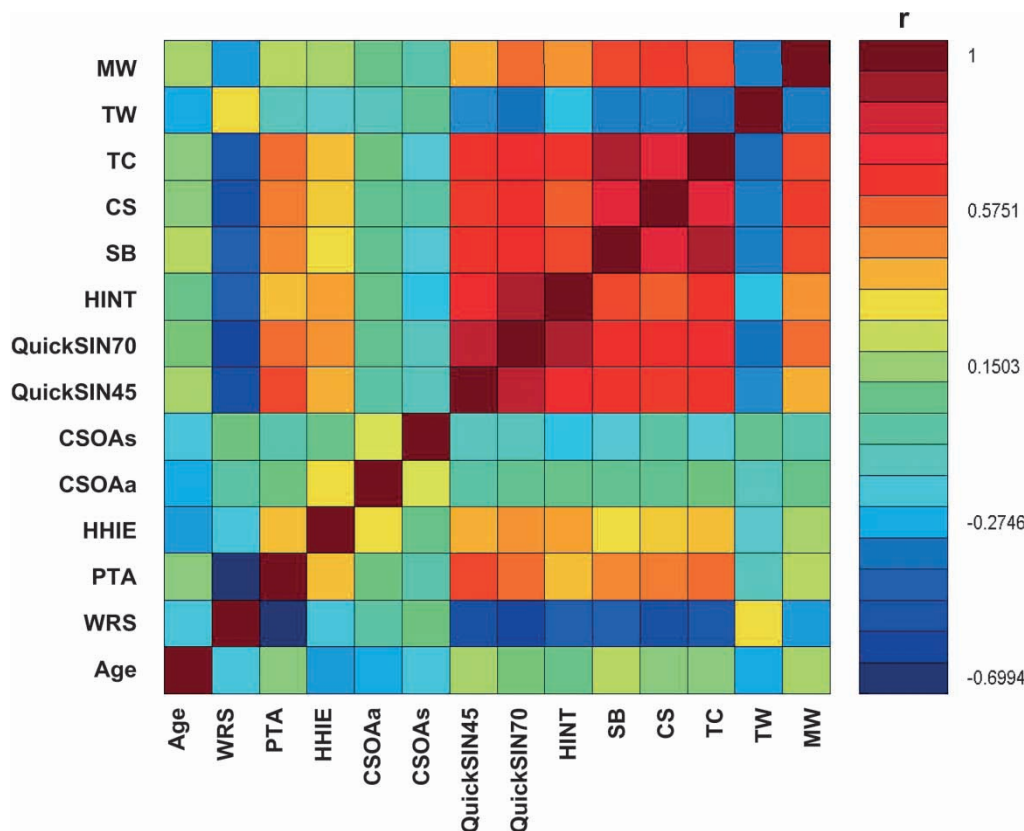


Figure 1. Correlation matrix for each of the baseline measures.

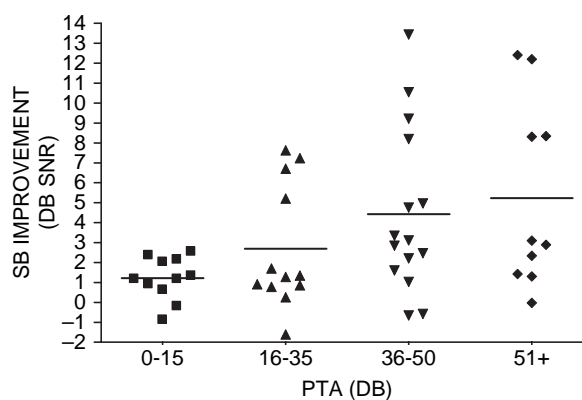
indicate a more positive correlation and blue shaded cells indicate a more negative correlation. For each cell, if the shading is darker, regardless of the color, the correlation is stronger. Data was imputed for missing values using two methods. The first is a standard method using the mean substitution method (Patrician, 2002; Hawthorne & Elliot, 2005). We repeated the analysis with an alternate method for imputing the data wherein we regressed the data from one variable on other variables and replaced the missing data using that regression fit. This procedure was repeated iteratively with different columns as the independent variable until the missing values converged. The process was conducted separately for the baseline and outcome variables. Results were not significantly different from using the mean, and those results were used in these figures.

Outcome measures assessed included standardized tests including the HHIE, CSOA, and QuickSIN, as well as on-task training scores from the SB, CS, TC, TW, and MW LACE™ tasks. Please note that high scores reflect better performance on the TW, MW, and monosyllabic word recognition score (WRS), whereas high scores on all of the remaining measures reflect poorer performance. In order to minimize procedural learning effects, the initial score on each LACE™ task was calculated based on the average presentation parameters for the first three days of training, with the initial ten trials discarded. For example, for the SB task, if the subject completed fifty trials in the first three days of training, the average SNR was calculated based on forty trials (following the discarded initial ten trials).

Age was not correlated with degree of hearing loss likely, because there was a wide range of hearing loss across age groups. Degree of loss, not surprisingly, was associated with baseline performance on the speech recognition tests (QuickSIN, HINT, and WRS) as well as the HHIE. Also, poorer word recognition scores were correlated with poorer baseline performance on all the speech related tests (QuickSIN and HINT) as well as the LACE™ speech related tasks (SB, TC, and CS), and with the TW and MW cognitive tasks.

*Correlation of subject characteristics and baseline test performance with compliance*

A stepwise algorithm for multiple regression model selection was used to find the best set of variables for prediction (Zar, 1999). Significance is defined by a  $p < 0.05$ . Age was significantly associated with the amount of time taken to complete the training program ( $r = -0.36$ ). Specifically, the younger subjects (25–50 years of age) took a greater number of days to complete the twenty training sessions than did the older subjects (above age 70). Also, the degree of loss (based on the pure-tone average of 500, 1000, and 2000 Hz) was related to the length of time it took to complete training ( $r = -0.48$ ). Subjects with greater hearing loss were more likely to complete the training early or on time, similar to the older subjects. Likewise, baseline scores on speech-in-noise outcome measures and the speech-in-babble (SB) and TC training tasks were statistically correlated with the number of days it took to complete training, in that subjects with poorer initial performances generally took less time to complete the training (QuickSIN 45 dB:  $r = -0.38$ ; QuickSIN 70 dB:  $r = -0.38$ ; SB:  $r = -0.32$ ; TC:  $r = -0.39$ ).

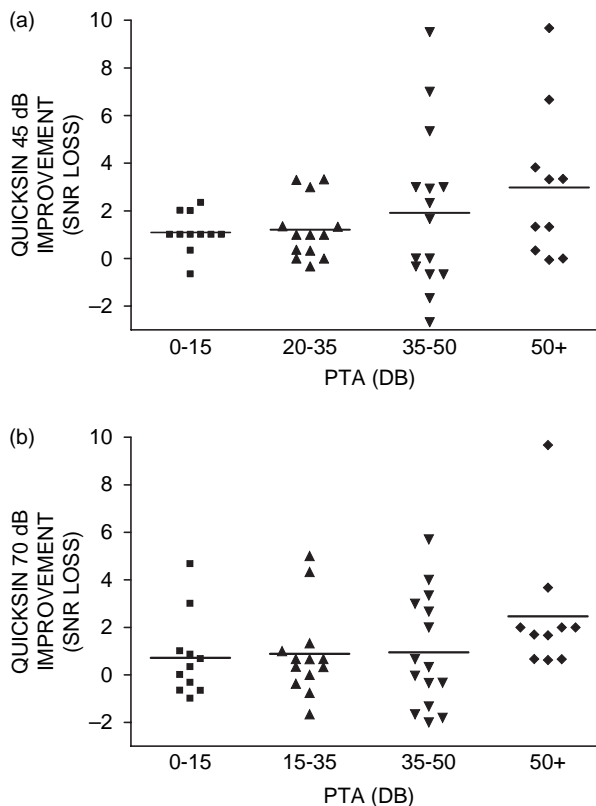


**Figure 2.** Grouped scatter plot showing improvement on the speech in babble training task (SB) as a function of pure-tone average (PTA). Each data point represents a single subject. Horizontal lines indicate the average SB improvement for each PTA group.

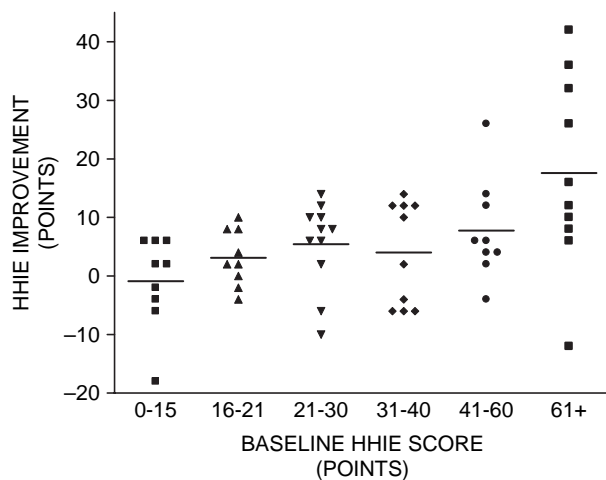
*Correlation of subject characteristics and baseline test performance with improvement*

**AGE**

There was no correlation with age and improvements for any particular test measures.



**Figure 3.** Grouped scatter plot showing improvement on the QuickSIN as a function of pure-tone average (PTA), for the 45 dB (Figure 3a) and 70 dB (Figure 3b) presentation levels. Each data point represents a single subject. Horizontal lines indicate the average QuickSIN improvement for each PTA group.



**Figure 4.** Grouped scatter plot showing improvement on the HHIE or HHIA as a function of the baseline HHIE or HHIA score. Each data point represents a single subject. Horizontal lines indicate the average HHIE or HHIA improvement for each group. Note that higher baseline HHIE scores reflect GREATER perceived handicap.

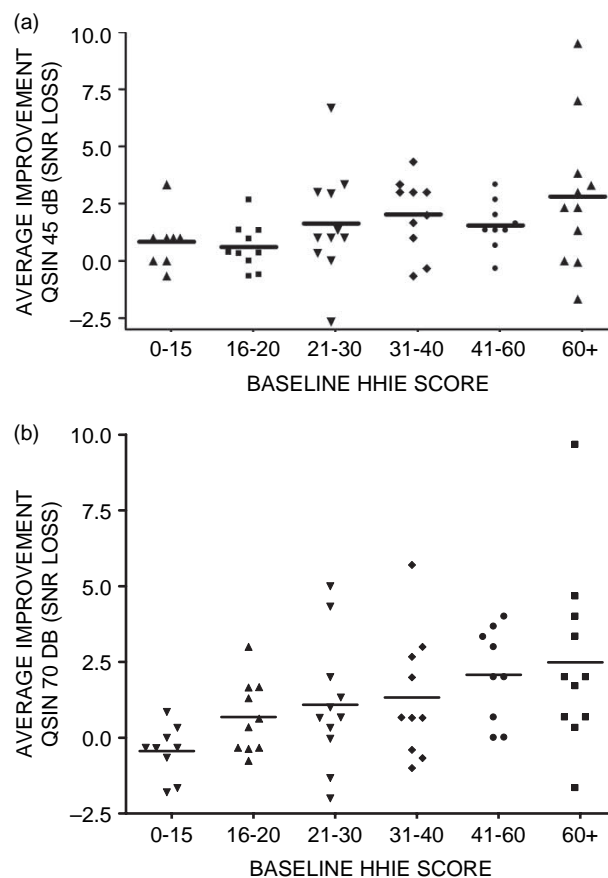
#### HEARING LOSS

There was not significant correlation between degree of loss and post-training improvement on the CSOA or the CS, TC, TW, or MW training tasks. Figure 2 and Figure 3 (a and b) show scatter plots indicating a positive correlation between degree of loss and improvements on the SB training task ( $r=0.36$ ) and QuickSIN (45 dB:  $r=0.33$ ; 70 dB:  $r=0.36$ ). It should be noted that not all subjects are represented on the scatter plots, as some of the sites collecting data did not report all hearing thresholds. Closer inspection of these scatter plots indicates that the regression for the QuickSIN improvements with 70 dB presentation is driven primarily by the subjects with the greater degree of hearing loss. In other words, there is more improvement shown for individuals with more severe hearing loss.

There is also an association between degree of loss and improvement on the HHIE; the more severe the loss, the greater the improvement on the self-perceived handicap scale ( $r=0.27$ ). Contrary to the correlation for QuickSIN being driven by the patients with more severe hearing loss, the HHIE correlation is driven by a floor effect for the subjects with normal hearing. When the analysis is conducted only with subjects with hearing loss, there is, somewhat surprisingly, no correlation between degree of loss and HHIE improvement ( $r=0.08$ ).

#### Perceived handicap, communication strategies and attitudes

The HHIE baseline scores were correlated with improvement on the post-training HHIE ( $r=0.49$ ) (Figure 4), and improvements on the QuickSIN (at 70 dB HL,  $r=0.48$ ) (Figure 5). In other words, individuals who initially perceived greater handicap improved more on their HHIE and QuickSIN scores after training. There is a positive correlation approaching, but not reaching, significance between the HHIE baseline score and QuickSIN improvement at 45 dB HL ( $r=0.22$ ), however this is driven by the improvement for the subjects with the poorest HHIE (more severe perceived handicap) score. The HHIE baseline was not correlated with any other improvement measures.

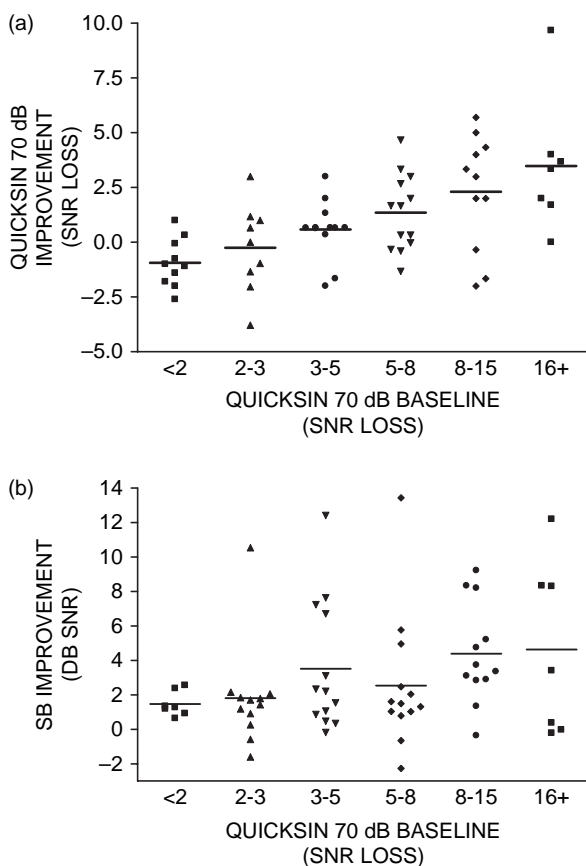


**Figure 5.** Grouped scatter plot showing improvement on the QuickSIN as a function of the baseline HHIE or HHIA score for the 45 dB (Figure 5, a) and 70 dB (Figure 5, b) presentation levels. Each data point represents a single subject. Horizontal lines indicate the average QuickSIN improvement for each group. Note that higher baseline HHIE scores reflect GREATER perceived handicap.

The CSOA strategies subscale (CSOA-S) baseline scores were correlated with improvement on that same scale ( $r=-0.30$ ). That is, those patients who were less likely to use effective communication strategies were more likely to improve on this scale. The CSOA attitude subscale (CSOA-A) baseline scores were not correlated with improvement on any outcome measure.

#### QuickSIN and HINT

The QuickSIN baseline scores were associated with improvements on the QuickSIN (45 dB:  $r=0.38$ , 70 dB:  $r=0.44$ ) and SB training task ( $r=0.26$ ). That is, the poorer the performance on the baseline QuickSIN, the more likely the subject was to improve on these measures. Examples of these relationships are shown in Figure 6 (a and b). An interesting deviation (not shown in the figures) appeared for the QuickSIN 45 dB presentation level data. It was shown that the group post-training average improvement was greatest for the subgroup of individuals with pre-training SNR losses of 8–17 dB. For subjects whose pre-training SNR loss was severe (i.e. more than 17 dB), improvement, while still present, was smaller. Improvement on the CSOA-S, however was negatively correlated



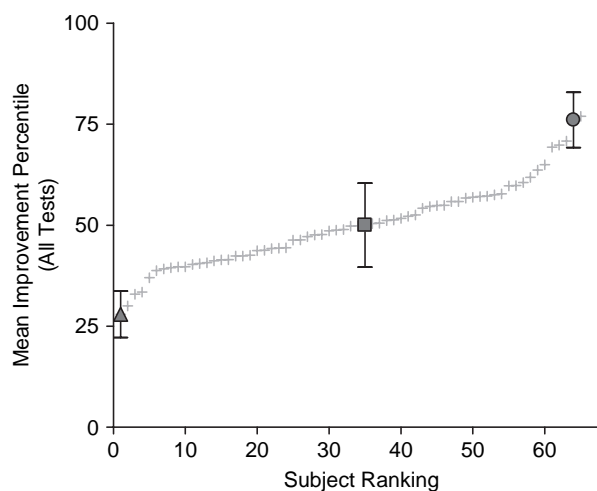
**Figure 6.** Grouped scatter plot showing improvement as a function of the baseline QuickSIN (70 dB presentation level) with improvement on the 70 dB QuickSIN (Figure 6a) and SB training task (Figure 6b). Each data point represents a single subject. Horizontal lines indicate the average improvement for each group. Note that higher baseline QuickSIN scores reflect POORER performance.

with the QuickSIN baseline scores ( $r = -0.36$ ), with those subjects with the most significant SNR losses showing lesser gains on this scale, possibly because those patients with more significant impairments had already integrated strategies into their lifestyle.

The HINT baseline score was associated with improvements on the QuickSIN at 70 dB ( $r = 0.42$ ). A negative correlation was found with the CSOA-S ( $r = -0.35$ ), with the group of subjects with the poorest HINT scores showing lesser gains. There were no other correlations found.

#### LACE™ training tasks

Subjects with poorer initial performance on SB obtained greater improvements in the SB training task ( $r = 0.69$ ), and the MW task ( $r = 0.40$ ). For the TC task there is a similar trend, i.e. poorer initial performance is associated with greater gains on the SB ( $r = 0.49$ ), TC ( $r = 0.24$ ), and MW ( $r = 0.32$ ) tasks. Poorer CS initial scores were associated with greater improvements on the SB ( $r = 0.38$ ), TC ( $r = 0.24$ ), CS ( $r = 0.43$ ), and MW ( $r = 0.37$ ) tasks. Initial scores on the TW task were correlated with improvements on the TC ( $r = -0.26$ ), TW ( $r = -0.43$ ), and



**Figure 7.** Mean improvement percentile for all subjects, plotted as gray cross-hatches from lowest to highest in rank. Three subjects are highlighted. Subject one (filled triangle) is a low performer, subject 2 (filled square) is an average performer, and subject 3 (filled circle) is a high performer. See text for details.

MW ( $r = -0.25$ ) tasks. Initial scores on the MW task were correlated with improvements on the SB ( $r = 0.26$ ) and MW training ( $r = 0.70$ ) tasks.

#### Overall improvement

In addition to assessing improvement on individual tasks, an overall improvement metric was created. To assess overall improvement, each subject's improvement on a task was given a percentile score based on the distribution of performance changes for all subjects. That is, the subject with the least improvement was assigned a score of 0 and the subject with the greatest improvement was assigned a score of 100. This was calculated for each task. Then, the average percentile across all tests was computed, resulting in a score that reflects overall performance. For example, Figure 7 depicts the ranking for three subjects. The scores for subject 1 (filled triangle) ranged from 2 to 48. Her poorest relative improvement (ranking of 2) was for the QuickSIN, while her best relative improvement (ranking of 48) was in the middle of the distribution of the TC training task. Subject 2 (filled square) ranked near the bottom (ranking of 2) for improvement on the MW training task, but he showed the largest improvement (ranking of 100) on the CS task. His other improvement rankings were in the middle of the distribution. Subject 3 (filled circle) showed relative improvement (ranking of 53) near the middle of the distribution for the TW task, and he obtained the greatest relative improvement (ranking of 100) on the SB training task. The average improvement scores for the remaining subjects are shown (cross-hatches). While there was no single individual whose percentile rank was 100 on each task, there was also no subject whose percentile rank was 0 on each task.

An analysis was then performed to determine if a method could be developed to predict from baseline or pre-test assessment scores which subjects would improve the most on LACE™ training. Correlative analysis of the overall improvement (as defined in the previous paragraph) with each of the

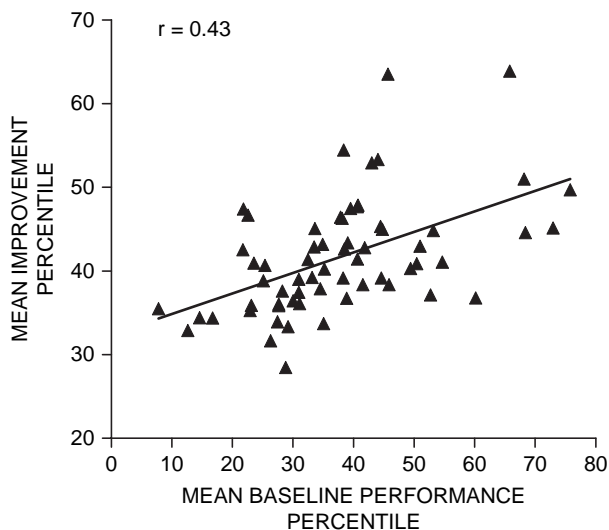
baseline variables was completed. A significant correlation is found between severity of hearing loss, CSOA-S ( $r=0.31$ ), SB ( $r=0.31$ ), CS ( $r=0.31$ ), TC ( $r=0.28$ ), TW ( $r=-0.26$ ) (all at  $p < 0.05$ ), and HHIE ( $r=0.48$ ,  $p < 0.01$ ), with overall improvement. Although these results are statistically significant, it is important to note there is considerable variability in the data.

## Discussion

Approximately 80% of the subjects improved to some degree on LACE™ training tasks, as well as on subjective and objective measures. While there were specific correlations—for example, poorer initial performance on the CS training task or greater perceived handicap on the HHIE was associated with greater overall improvement—performance on any particular task or test did not reliably predict an individual’s overall improvement because of variability in performance. Therefore, clinical expertise and experience, as well as information obtained from counseling, is crucial when deciding who should participate in computerized aural rehabilitation.

In this study, those subjects with more to gain generally gained more. These findings are in agreement with other assessments of aural rehabilitation (Kricos & Holmes, 1996; Walden, 1981). An exception was observed in the QuickSIN results at 45 dB, where the subjects with the greatest impairments (highest SNR losses) showed less improvement than those subjects with slightly less impairment, presumably due to the fact that these subjects had some issues with audibility that could not be overcome with training.

Figure 8 shows the association of the overall initial performance with the overall improvement (derived in the same manner as the overall improvement, i.e. percentiles on the initial test scores were averaged across all measures with low baseline percentiles indicating better performance on the baseline tests). Those subjects whose initial outcome performances were on the better end of the distribution generally improved less than the other subjects, presumably due to ceiling effects on certain



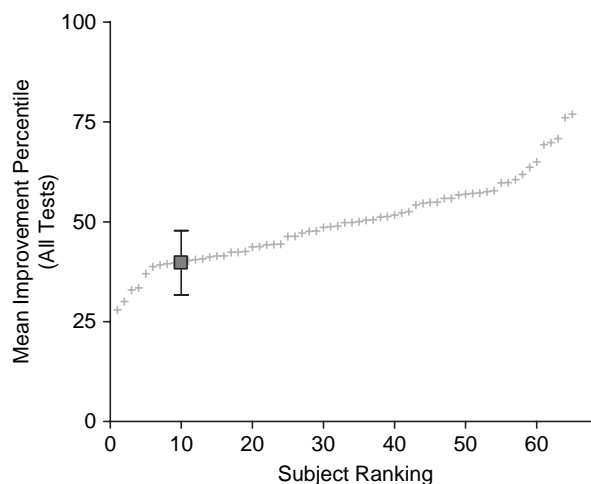
**Figure 8.** Mean improvement percentile plotted as a function of the mean baseline performance percentile. Each filled triangle is a single subject. Solid line indicates best-fit.

Variables predicting outcomes on listening and communication enhancement (LACE™) training

measures. Those on the poorer end of the performance distribution were likely to demonstrate larger gains in performance. This could be due to a regression toward the mean effect, however, since it is seen across multiple tests, this explanation cannot solely account for this trend.

It would be a mistake, however, to assume that training should be reserved only for patients with significant deficits and poor communication skills. Even small gains can be important to the subject. For example, consider the data from subject 18, as illustrated in Figure 9. This individual was a 75 year-old woman with a mild hearing loss and excellent word recognition scores. Her performance gains were modest, (filled square). She showed greater-than-average improvement on the CS and TW tasks, but did not show improvement on the other speech training tasks or on the QuickSIN. However, she improved by 14 points on the HHIE (from 30 to 16) and produced a significant improvement in the attitude subscale of the CSOA. Additionally, on a subjective questionnaire completed at the conclusion of training, she reported that she was more likely to enter difficult listening situations, more confident in conversations, and better able to concentrate and for longer periods of time. She further indicated that she perceived considerable improvement from the training. It is difficult to determine in cases such as this whether the subject experienced some sort of placebo effect, or whether the gains on the training tasks were significant enough to result in subjective improvement. In this case the subject improved more than the average subject on a measure of auditory memory, and on a measure of speech with a single competing speaker. It is possible that improved memory skills and improved ability to focus on a speaker at the expense of another (executive control) was the basis of this subject’s reported improvements.

Computerized training may not be feasible for every patient. It would be useful to be able to predict which subjects are more likely to commit to participating in, and ultimately completing, a training program. The data in this study indicate that subjects with greater hearing loss and older subjects were more likely to complete the training on time or early. Based on informal



**Figure 9.** Mean improvement percentile plotted for each subject as in Figure 7. Subject 18 is shown in the distribution as a filled square.

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feedback from subjects, there was a trend that subjects with greater hearing loss had more motivation to complete training. Younger subjects were more likely to report that they had insufficient time to devote to the training program, and were more likely to travel and have other commitments that conflicted with training. Older subjects were more likely to have time to devote to the training and were more likely to make training a priority in their daily schedule. That does not necessarily imply, however, that older subjects will be more willing to participate in aural rehabilitation training programs. Some elderly patients can be intimidated by the training process, particularly when computers are involved. However, it was found that once the first few sessions were completed, most subjects successfully finished the training.

The motivation to improve listening skills may be the most critical factor for obtaining a commitment to complete LACE™ or any training program. This, as well as other psychosocial variables, was not quantified in this project. These may include lifestyle, available free time, or, either internal (the desire to enhance one's listening skills), or external (the desire to please family members) incentives to complete the training. The benefit-to-cost ratio for completing training may be different for each patient and should be assessed, as is common during hearing aid selection. These variables certainly warrant investigation as they pertain to AR, and computerized AR and auditory training programs. Future studies of LACE™ and other AR programs should include establishment of motivational factors, importance of multimedia and other sensory inputs, and the refinement of training parameters.

At this time, LACE™ is not appropriate for patients with profound loss or with limited language skills because of the content of the training material. This must be a consideration for rehabilitation programs. New content for LACE™, for example, could be developed for a number of languages and for specific populations, such as cochlear implant recipients.

It would be hazardous to conclude that the results from this study can be generalized to other forms of aural rehabilitation, such as group education. However, certain similar patterns can be presumed with reasonable certainty. LACE™, particularly when coupled with a hearing aid fitting, may require greater self-motivation than other rehabilitative treatments because it is home-based as well as time consuming. Unfortunately, improvements in technology often are accompanied by disproportionate increases in hype and, therefore, encourage unrealistic expectations. Patients frequently have the belief that the product (i.e. the hearing aid) and the professional delivering that product (i.e. the audiologist) comprise the totality of the outcome. As such, there has been decreasing conviction that active participation from the patient is necessary. For programs to succeed, audiologists must return to their original rehabilitative roots. The long-term future of our profession may depend on the motivational and counseling skills of the professional.

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