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SUBJECTIVE VERSUS OBJECTIVE MEASURES OF DAILY LISTENING ENVIRONMENTS

by

Jennifer Suzanne Taylor

A Capstone Project submitted in partial fulfillment of the requirements for degree of:

Doctor of Audiology

Washington University School of Medicine Program in Audiology and Communication Sciences

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Abstract: The present study examined hearing impaired listeners' subjective perceptions of listening environments through a listening questionnaire and compared these results to objective measures mimicked by the questionnaire in the datalogging device SAM (Sound Activity Meter). Results indicate audiologists should not rely on patient reports of "typical" listening environments for hearing aid selection as significant discrepancies were present between several of the subjective and objective measures.

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INTRODUCTION

Hearing aid technology continues to progress with advances in digital signal processing (DSP). Advances in technology have also increased the expense of hearing aids due to providing additional "features" (Kochkin, 1999). These features may include expansion, noise reduction, adaptive directional microphones, feedback cancellation, and real-time calibration of directional microphones. A more recently introduced feature is *datalogging* allowing audiologists to view activity of hearing aid use and measures of the users' listening environments. Datalogging in hearing aids provides specific information to audiologists such as total hours of hearing aid use and the average volume control adjustments made by the patient in various listening environments or programs (memories). The datalogging feature can also provide useful information to the audiologist for counseling purposes in order to instruct the patient on appropriate program changes depending on his/her listening environment.

Datalogging was introduced in 1987 with the development of the 3M MemoryMate hearing aid by Hearing Health Program/3M and Diaphon (Mangold et al, 1990). The MemoryMate was utilized in many studies evaluating the efficacy of multiple-memory hearing aids in the late 1980s and early 1990s (Mangold et al, 1990; Ringdahl et al, 1990; Ringdahl, 1994). Eight memories were available to program for various listening conditions and were accessed through a push button. When a memory was selected, datalogging measures began in three ways. The first measure was made when the program was accessed for more than two minutes. This allowed documentation of how many times each memory was accessed. The second log recorded the total time the wearer was in each memory. A final log was made each time the memory push button was pressed. The purpose of the latter log was to evaluate if the memory button was being accessed a proportional amount compared to the total sum of logs. If

this proportion was too high, the patient was not properly changing memories or could not find an appropriate memory for the listening situation.

Research using the MemoryMate was extensive regarding the usefulness of multiple-memory hearing aids. The first clinical study with the MemoryMate was conducted by Mangold et al (1990). The primary purposes included identifying subjective preferences of sound quality for the MemoryMate compared to the subject's own hearing aid, and measuring word recognition scores between the MemoryMate and the subject's own hearing aids. Results indicated 11 of 13 (84.6%) subjects preferred the MemoryMate to their own aid on sound quality questionnaires that addressed multiple listening environments (divided into three main groups: comfort, normal, and speech and noise). The remaining memory was reserved for a t-coil program. Word recognition scores were completed using the Synthetic Sentence Identification (SSI) Test (Speaks and Jerger, 1965) in speech-shaped noise according to Hagerman (1984). The purpose of this test is to determine the signal to noise ratio (SNR) that generates a score of 50%. This method was modified (according to Hagerman, 1984) and word recognition scores were measured at the same SNR (average of -3.2 dB SNR) for the MemoryMate and the subject's own hearing aid. Performance on word recognition testing was significantly improved in the MemoryMate compared to the patient's own aid in 11 of 13 (84.6%) of the subjects. The datalogging feature was used to assist in reprogramming the hearing aid based on subjective preferences.

Similar studies were conducted by Ringdahl (1994) and Ringdahl et al (1990) to examine subjective preferences for each of the eight memories in specific listening environments, (i.e., television, music, distant conversation, noisy conversations, and party). The Ringdahl et al, 1990 and Ringdahl, 1994 studies determined the optimal hearing aid fitting for speech intelligibility

and listening comfort. The subjects in the Ringdahl et al (1990) study preferred the MemoryMate in 74% of the listening conditions (based on questionnaire responses in the areas of hearing ability and sound quality) and 21% of the conditions were noted as undetermined listener preferences. Variable results were evident in noisy conditions, and subjects did not indicate significant preferences for the MemoryMate. Word recognition was measured with the Synthetic Sentence Identification Test in speech-shaped noise for the subject's own hearing aid and the MemoryMate in two preferred memories (as determined from the questionnaire responses). Sentences were presented at a comfortable level in the range of 62 and 79 dB SPL. Subjects improved significantly with the MemoryMate in the preferred listening memories with mean scores of 55.5% and 58.0% respectively, compared to mean scores with their own aid of 48.5%. In a latter study, Ringdahl (1994) examined the total hours per day the aid was worn for 29 subjects. The author defined a "reliable" program memory as a program that was used for more than 30 minutes per day, and even more "reliable" if subjects used the program for more than 60 minutes per day. Results suggested subjects wore the aid for 7.9 hours per day, and subjects benefited from two to four program memories for specific listening environments.

Patient perceptions of hearing aid use time have also been examined to approximate the success of a hearing aid fitting as well as determining the need for further modifications in programming. The MemoryMate and other datalogging mechanisms on hearing aids were modified to include an internal datalogging device to examine subjective perceptions regarding hearing aid use time compared to objective measurements. Brooks (1979) conducted a study to evaluate objective hearing aid use time with a hearing aid modified with an internal clock to record the number of times the hearing aid was turned on/off, and how many total hours the hearing aid was worn. The purpose of the study was to determine if extensive counseling on

hearing aid use increased the amount of time subjects wore hearing aids. Results suggested subjects with a moderate amount of counseling made significant improvements in the use time of their aids. Brooks obtained the subjective reports during interviews at each appointment in which the hearing aid data was read. Results from the 60 subjects indicated subjects on average, overestimated hearing aid use time by approximately one hour. The author recognized potential problems may have affected results, including the derived, weighted values of subjects' reports. Objective and self-report measures of hearing aid use time were also evaluated in a study conducted by Haggard et al (1981). The experimental hearing aids were equipped with a counter to record the on/off switch activation as well as hearing aid use time. Subjects were questioned regarding how many hours per day the hearing aids were worn. Results indicated subjects overestimated hearing aid use time on average by approximately 0.1 hours. Variable results between the Haggard et al (1981) and Brooks (1979) studies were attributed to clinician/subject rapport established over the period of a year prior to data collection. In addition, results in the Haggard et al (1981) study were estimated hours of use rather than a formal interview or questionnaire as used in the Brooks (1979) study.

Research utilizing the datalogging feature of MemoryMate aids has also been valuable in determining the success of a hearing aid fitting. Humes et al (1996) evaluated 20 adults to determine the reliability and stability of hearing aid outcome measures. Subjects wore MemoryMates to measure objective hearing aid use, and questionnaires were administered to determine subjective hours of use. Datalogging results indicated subjects overestimated actual hearing aid use time by approximately four hours per day. Taubman et al (1999) investigated patient perceptions of actual hearing aid use time compared to subjective patient recollection. Twenty four subjects were fit with Sonar programmable multi-memory hearing aids and divided

into two groups: 1) the experimental group was aware actual hearing aid use time would be objectively verified; 2) the control group was informed they would be asked a series of questions including how often they used the hearing aids. The control group completed a modified Abbreviated Profile of Hearing Aid Benefit (APHAB) (Cox and Alexander, 1995), to determine hearing aid use time. Questions were added to the APHAB questionnaire that addressed how many batteries were used and how many hours per day the hearing aid was used. Results indicated the group that was unaware of the objective measurements (control group) both overestimated and underestimated actual hearing aid use time, with the mean overestimation of 3.7 hours per day. The experimental group overestimated actual hearing aid use time by a mean of 1.1 hours. Subjects who were aware of the objective measurement (experimental group) were more accurate in their determination of hearing aid use time and also demonstrated less variable responses. These results have important implications for clinical interview techniques that form a foundation for hearing aid selection. For example, interview techniques implemented to determine the necessity for advanced hearing aid features may need to be modified to account for discrepancies between actual and perceived acoustic environments. Datalogging capabilities have provided researchers and clinicians with information on subjective preferences for hearing aid programming, and documented variability in patient perceptions of hearing aid use time.

Datalogging is now available in many hearing aids, and utilizes more advanced capabilities beyond hours of use. In addition to hours of use, current datalogging capabilities include logging manual program changes as well as automatic program switching available in high-level technology. Another benefit of datalogging may be its contribution to hearing aid feature selection **before** the hearing aid fitting. Some datalogging features quantify overall input levels (in dB SPL) as well as categorizing inputs into different listening environments (speech

alone; noise alone; speech and noise; listening in a car; listening to music; listening in the office; etc).

The Sound Activity Meter (SAM) manufactured by Oticon (Figure 1) is an advanced datalogging device that records acoustic environments with respect to listening in quiet, speech only, speech in noise, and noise only (Figure 2).

Figure 1. SAM with battery door and two microphones (Flynn, 2005).

The device also quantifies the percentage of time an individual is in an environment with a specific input level. This individual identified in Figure 2 was found to spend 38% of the recording time in quiet, 42% of the time in speech only, 8% of the time in speech in noise, and 12% of the time in noise only. In this example, 80% of the individual's time was spent in categories of quiet and speech only without the presence of background noise, indicating directional microphone technology is not required in a significant portion of the time. These four main categories are identified by different signal levels through coordinating the color of the shaded sound level histogram to the color of the percentage of each category (i.e., quiet is green, speech only is blue, speech in noise is yellow, and noise only is grey). The sound level histogram not only indicates the category of signal by color (quiet, speech only, speech in noise, and noise only), but also differentiates the input level in each category. In the individual

identified in Figure 2, a 50-60 dB SPL level was identified as speech only between 4-17% of the time (a total of 13% of the time in a 50-60 dB SPL level), and was categorized as noise for approximately 19-22 % of the time (4% of the time in a 50-60 dB SPL level). The remaining categories were quiet for 4% of the time and speech in noise for 1% of the time. The percentages for each of the categories can be summed to find a total percentage of time in the 50-60 dB SPL level to be 22% of the time, as illustrated by the height of the entire bar circled in red on Figure 2.

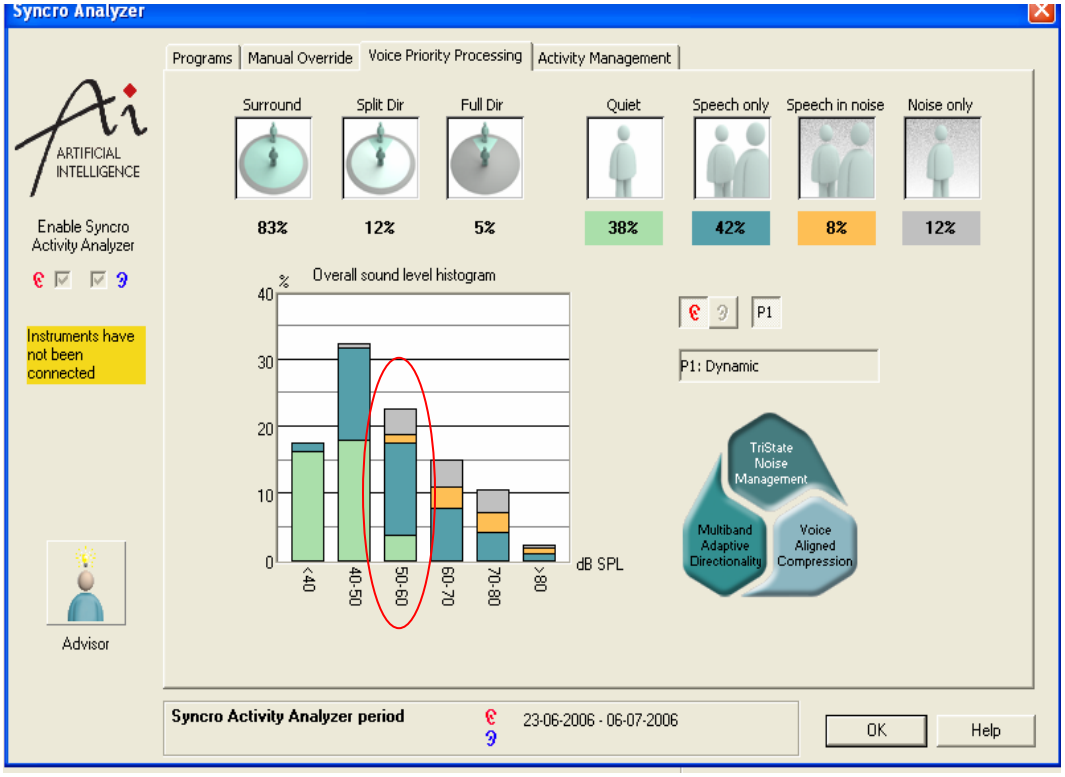

Figure 2. Oticon Genie software screen of SAM data.

The device is worn on the lapel of a shirt/blouse with a straight pin and hook. The data SAM provides can be utilized to incorporate specific hearing aid features toward the individualized amplification process. SAM could be worn to determine the necessity of a feature such as adaptive directional microphone technology. In this case, let us assume SAM reports the patient is in speech in noise 80% of the time. With this information, the audiologist can counsel

the patient on the advantages of adaptive directional microphones in these difficult listening situations, and compare to how this is different than an individual who is spending 80% of the time in quiet (e.g., directional microphone technology may not be required and thus the hearing aids may be more appropriate and less expensive).

Flynn (2005) illustrated the necessity of audiologists to thoroughly understand acoustic diversity **before** selecting amplification features for patients. Flynn (2005) suggests using SAM to enhance discussions with patients beyond hearing loss, and address the overall topic of communication demands. These listening demands may relate to the variety of acoustical environments a patient encounters every day, or once a week, or once a month. In this manner, more realistic expectations can be addressed specifically for the patient **before** the hearing aid fitting. After the hearing aid fitting, audiologists may use the datalogging features available in hearing aids to evaluate specific fine tuning adjustments or even examine the complexity of patient's listening environments. Flynn (2005) documents the following patient populations as ideal candidates for SAM:

1. An unmotivated individual aware of his/her hearing problems. SAM increases patient involvement between the time of the initial evaluation and hearing aid fitting by having the patient participate by wearing SAM for this three week period.
2. A motivated hearing aid user interested in advanced technology. By illustrating the patient's variety of listening environments, audiologists can more appropriately counsel patients on beneficial features specifically for these listening environments. For example, a patient that is found to spend 75% of his/her time in speech in noise could benefit from directional microphones and hearing assistive technology (HAT).

3. A current hearing aid user not motivated to try new technology. SAM recordings can illustrate features associated with advanced signal processing. For example, SAM may indicate a patient is in loud continuous noise for extended periods of time. Knowing this information the audiologist could suggest advance signal processing with enhanced noise reduction features to address the need of the individual.
4. Family members that may benefit from visual reinforcement of the benefits of advanced signal processing.

Several studies have considered the differences between patient perceptions of hearing aid use time compared to actual hearing aid use time (Brooks, 1979; Haggard et al, 1981; Taubman et al, 1999). However, the purpose of two of those studies (Brooks, 1979; Haggard et al, 1981) was not to evaluate the datalogging systems invoked in the MemoryMate, but to determine the success of multi-memory hearing aids. Additional studies examined subject performance in various listening environments, but did not determine subjects' perceptions of those listening environments (Ringdahl et al, 1990; Ringdahl, 1994). Examining complex data available in current datalogging, suggests an even larger variability in patient perceptions of daily listening. The purpose of the current study was to determine if statistically significant differences are present between subjective reports and the objective measures of listening environments obtained from SAM. This study reflects on the accuracy of subjective reports of "typical" listening environments that are currently being used by audiologist to make these decisions. Research questions for the current study include:

Are statistically significant differences present between:

a. An <u>initial</u> report of "typical" listening environments as measured by a questionnaire taken ***<u>before</u>*** SAM was worn and the listening environments measured by SAM?

b. A repeat report of "typical" listening environments as measured by the same questionnaire taken ***after*** SAM was worn and the listening environments measured by SAM?

c. Reports of "typical" listening environments when subjects were aware their environment was being measured (question b) compared to when subjects were unaware that these measures would be taken (question a)?

METHODS

Subjects

Twenty adult subjects were recruited with inclusion limited to subjects who were candidates for amplification. Subjects were recruited from the Adult Audiology Clinics at Washington University School of Medicine in the Center for Advanced Medicine and Central Institute for the Deaf. Subject inclusion was independent of the configuration, type, and degree of hearing loss. Inclusion criteria specified adults in the age range of 18-85 years scheduled for audiologic evaluation and/or hearing aid evaluation. Subjects were native speakers of English and were able to read and comprehend the listening questionnaire. It is important to note that while twenty subjects began the initial process for the study, five subjects dropped out. These dropouts occurred due to loss of the device (4), and corrupted data due to software incompatibility (1). The final 15 subjects were between the ages of 20 and 82 years of age (mean = 64.3 years, standard deviation = 18.5 years). Table 1 reports subject demographics including gender, experienced versus non-experienced hearing aid users, the period of time experienced subjects may have worn hearing aids, and how long they have worn their current hearing aids. All subjects were approached during the audiologic evaluation/hearing aid evaluation and were not compensated for their participation

Table 1. Demographic data for 15 subjects.

	Age	Gender	Experience with Hearing Aids	Years of Experience	Hearing Aid Manufacturer
Subject			**Y/N**		
1	**68**	**F**	**N**		
2	**69**	**M**	**N**		
3	**71**	**M**	**Y**		**Siemens**
4	**68**	**M**	**N**		
5	**80**	**F**	**Y**	**2**	**Siemens**
6	**20**	**M**	**N**		
7	**82**	**M**	**N**		
8	**82**	**M**	**Y**	**5**	**Audina**
9	**77**	**M**	**Y**	**15**	**Oticon**
10	**33**	**M**	**N**		
11	**73**	**M**	**N**		
12	**70**	**F**	**N**		
13	**73**	**F**	**Y**	**12**	**Starkey**
14	**57**	**F**	**N**		
15	**42**	**M**	**N**		
	Age			**Years**	
Subject					
Mean	**64.3**			**8.5**	
SD	**18.5**			**6.0**	

Procedures

This study received Investigational Review Board (IRB) approval at Washington University School of Medicine in October 2006. A comprehensive audiometric evaluation and responses to the initial questionnaire was performed prior to obtaining written informed consent. Figure 3 is a mean audiogram for the 15 subjects were averaged right and left thresholds for each frequency. T-tests were completed on the mean scores for the right and left ears for each test frequency (250 Hz, 500 Hz, 1000 Hz, 2000 Hz, 3000 Hz, 4000 Hz, 6000 Hz, and 8000 Hz) and

no statistically significant differences were found. The mean audiogram indicates a mild to moderately-severe gradually sloping sensorineural hearing loss.

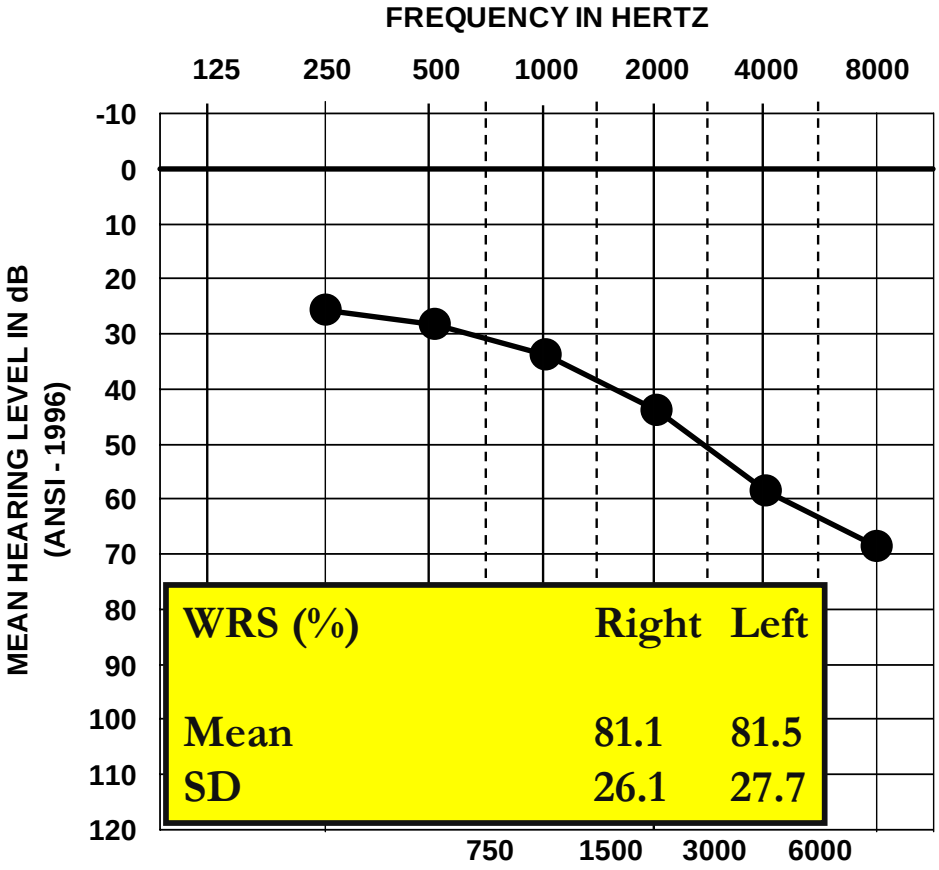

Figure 3. Mean audiogram illustrating a mild to moderately-severe gently sloping sensorineural hearing loss.

Due to the methodology of the study, informed consent was obtained **after** completing the first questionnaire. Subjects completed the initial questionnaire under the assumption the questionnaire is a routine procedure of the appointment to create the most natural clinical environment for data collection. After completing the initial questionnaire, subjects were informed of the study and had the option to continue with his/her participation or to decline participation. If subjects chose to participate, a SAM device was assigned to the subject with oral and written instructions on the care and maintenance of SAM. Subjects were provided with #10 batteries, and instructed to change the battery every seven days to ensure recordings during at

least eight hours per day. Subjects returned in three weeks to have data from SAM read by the Oticon Genie software and saved to a password encrypted flash drive. Data was downloaded from SAM by connecting the SAM to a NOAH interface box and data was viewed in either Oticon eCAPS or Genie software. This second appointment also required subjects to complete the second questionnaire, which was identical to the first questionnaire. The first and second questionnaires were compiled along with the measurements obtained from SAM and entered into the same spreadsheet for future statistical analysis.

The listening questionnaire (see Appendix A) was developed to mirror the data measured by SAM. Question 1 relates to the percentage of time the subject was in a quiet environment. An example was provided in the questionnaire of being in a quiet study or office. SAM also records the percentage of time (refer to Figure 2) in quiet. Question 2 asks the subject about the percentage of time in speech in background noise, which SAM also provides. Question 3 and 4 refer directly to the SAM data (percentages shown in grey and blue in Figure 2), inquiring about noise only and speech only, respectively. The final three questions of the questionnaire were derived from the information provided by the sound level histogram. Question 5 addressed the percentage of time listening to a quiet input signal with minimal background noise. The example provided was in an office/study with a fan turned on in the background. The sound level histogram divides the input signals into levels of noise re: dB SPL. The researcher chose to arbitrarily group the first two bars of the sound level histogram (less than 40 dB SPL and 40-50 dB SPL) to compare to Question 5 on minimal background noise. Question 6 was developed from grouping the second and third bar graphs in the sound level histogram (50-60 dB SPL and 60-70 dB SPL). Question 6 required subjects to report on the percentage of time they were attending to an average level input signal plus background noise. The example provided was

listening to the radio with the dishwasher running in the background. The final question addressed a loud level input signal plus loud background noise. The example was standing on a busy street with a bus pulling up to the curb. This question was developed to relate to the last two bar graphs on the sound level histogram in the SAM software (the 70-80 dB SPL bar was combined with the greater than 80 dB SPL bar).

RESULTS

Main Effect of the Method of Data Collection: (Pre, SAM, Post)

A three (method of data collection: Pre, SAM, Post) by seven (listening environments) within-subject analysis of variance (ANOVA) was completed to determine if significant differences were present between methods of data collection (Pre, SAM, Post). The grand means for methods of data collection collapsed across the seven listening environments are reported in Figure 4.

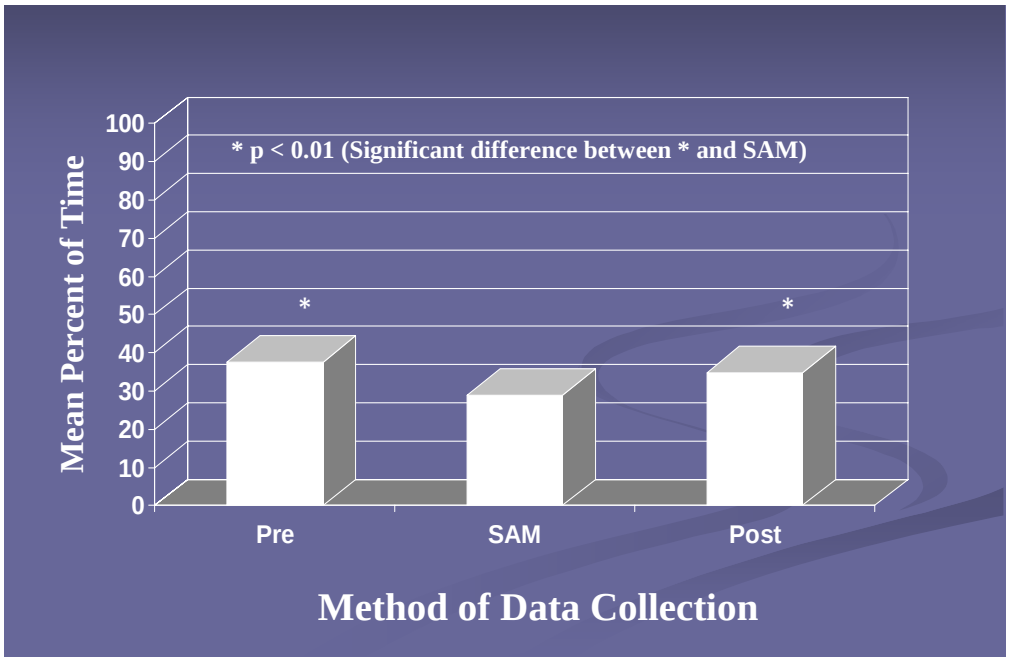

Figure 4. Grand means of method of data collection averaged across listening environments.

Statistically significant differences were found between the means of methods of data collection ($F = 4.3$; $dF = 2/28$; $p < .03$). Post-hoc analysis using t-tests indicated significant differences ($p<0.01$) were found between the Pre-questionnaire data and the objective data obtained from SAM, as well as the Post-questionnaire data and the objective data obtained from SAM. In both cases, the percent of time spent in each listening environment reported by subjects was significantly greater than the percent of time reported by SAM. That is, subjects overestimated the percent of time, averaged across the seven listening environments on the Pre-questionnaire responses and Post-questionnaire responses when compared to the mean data collected from objective SAM measurements. If reported in this manner to their audiologist, it is probable that the audiologist, on average, would have recommended hearing aid features that may have been inappropriate (e.g., recommend directional microphones for listening in noisy environments). Finally, significant differences were not found between the Pre and Post questionnaires.

Main Effect of Listening Environment

A seven (listening environments) by three (methods of data collection) within-subject analysis of variance (ANOVA) was completed to determine if significant differences were found between listening environments when averaged across the three methods of data collection. The grand means for each listening environment collapsed across all methods of data collection are reported in Figure 5.

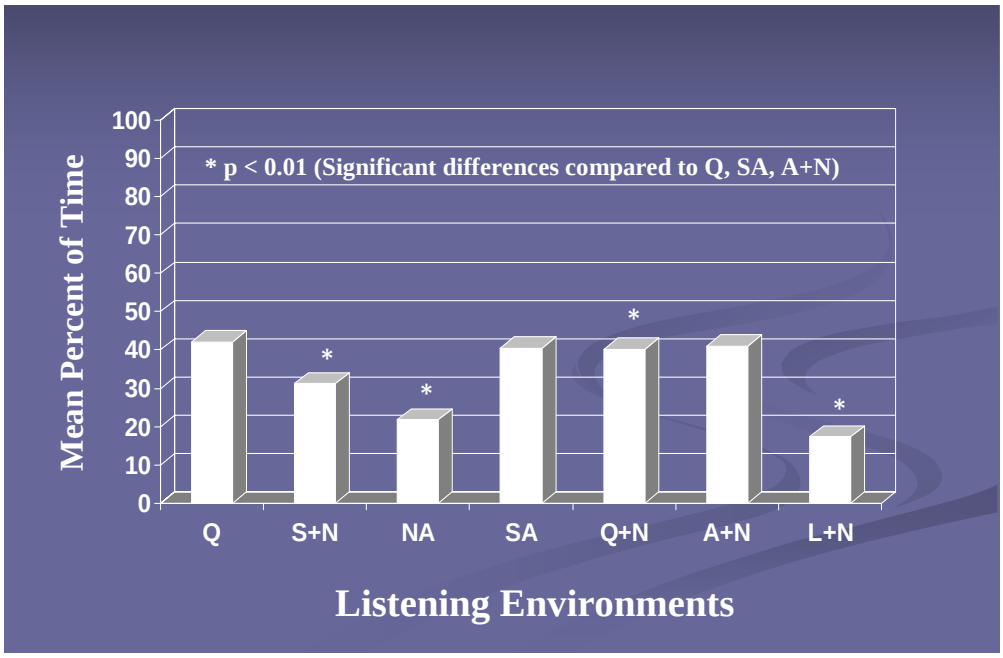

Figure 5. Grand means of listening environment averaged across method of data collection.

Statistically significant differences were found between the means of the listening environments ($F = 14.7$; $dF = 6/84$; $p < 0.001$). Post-hoc analysis using t-tests indicated significant differences ($p < 0.01$) were found between the listening environments of speech in noise (S+N), noise alone (NA), quiet input signal plus noise (Q+N), and loud input signal plus noise (L+N) when compared to the means of listening environments of quiet (Q), speech alone (SA), and average input signal plus noise (A+N). In listening environments of S+N, NA, Q+N, and L+N all average results were significantly less than the overall means of quiet (Q), speech alone (SA), and (A+N) indicating that subjects, on average, perceived less percent of time exposed to these four listening environments than the remaining other three listening environments. Significant differences in data were found to occur in four listening environments (S+N, NA, Q+N, and L+N) when averaged across the three methods of data collection (Pre, SAM, and Post) whether the data was subjective questionnaire responses or objective SAM measures. Overall differences

in means of listening environments were present in four listening environments, and the remaining three environments did not yield significant differences in mean data.

Interaction between Method of Data Collection and Listening Environment

A three (method of data collection: Pre, SAM, Post) by seven (listening environment) within-subject analysis of variance (ANOVA) was completed to determine if significant differences were present in the interaction of methods of data collection and listening environments. The grand means for the interaction of method of data collection and listening environments are reported in Figure 6.

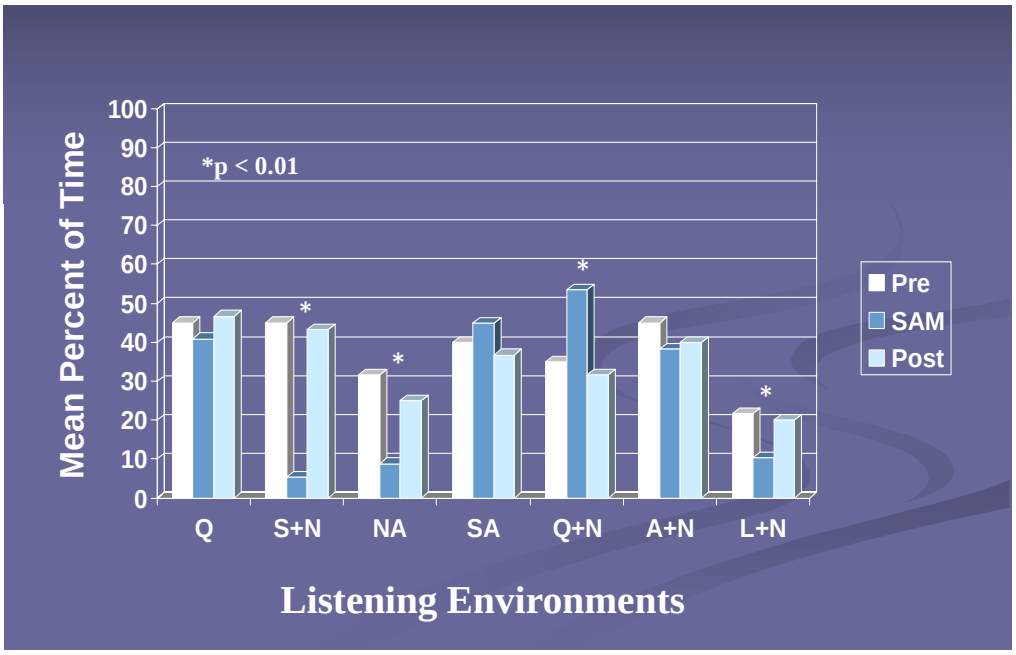

Figure 6. Interaction of method of data collection and listening environments.

Statistically significant differences were found in the interaction between the means of method of data collection and listening environment ($F = 13.5$; $dF = 12/168$; $p < 0.001$). Post-hoc analysis using t-tests indicated significant differences ($p < 0.01$) were found in the interaction of method of data collection and listening environment. Listening environments that yielded significant differences included speech in noise (S+N), noise alone (NA), quiet input signal plus noise (Q+N) and loud input signal plus noise (L+N). In these listening environments statistically

significant differences were found between the Pre and Post questionnaire data and the objective SAM measures. In the S+N, NA and L+N listening environments, subjects reported the percent of time spent was greater than recorded by SAM. On the other hand, for the Q+N listening condition, the data recorded by SAM was significantly higher than reported by the subjects on their Pre and Post questionnaires. Subjects underestimated the time spent in Q+N when compared to mean data reported by SAM. For the Q, SA, and A+N listening environments no significant differences were found between the two questionnaires and SAM.

Pre-SAM questionnaire versus SAM

A separate analysis of variance (ANOVA) was completed to evaluate differences between the results on the Pre-SAM questionnaire and SAM. Additional analysis was completed for this comparison because this demonstrates the "typical" clinical situation. During a hearing aid evaluation audiologists assess listening needs through a listening questionnaire and make hearing aid feature selection based on the reported listening needs. The Pre-questionnaire versus SAM condition represents the most "typical" clinical environment to generalize the current data to make clinical implications that account for these discrepancies when decisions are made regarding hearing aid feature selection/activation.

Statistical Effects in the Pre-SAM questionnaire and SAM data

A two (method of data collection: Pre and SAM) by seven (listening environments) within-subject analysis of variance (ANOVA) was completed to determine if significant differences were present between methods of data collection (Pre and SAM) and the seven listening environments. Statistically significant grand means are reported as 37.6% and 28.9% for the Pre-questionnaire and SAM data, respectively ($F = 15.7$; $dF = 1/14$; $p < 0.001$). Listening environment effects were analyzed (across methods of data collection) in the ANOVA, and the

means are statistically significant in the Pre-questionnaire versus SAM data ($F = 19.9$; $dF = 6/84$; $p < 0.001$). Figure 7 reports the effect of listening environment in the Pre-questionnaire versus SAM condition.

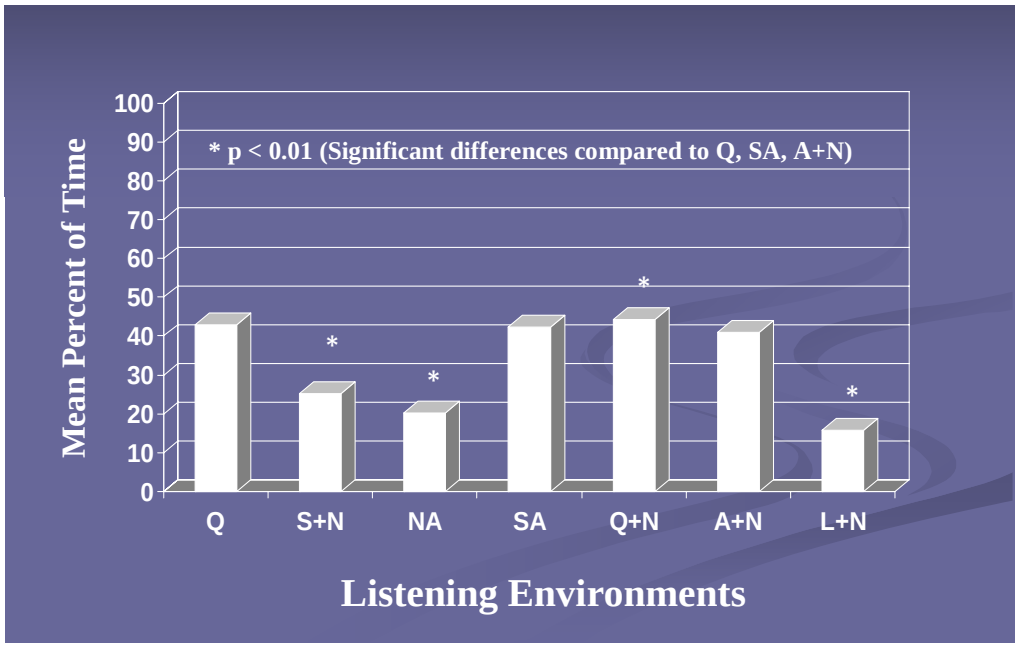

Figure 7. Pre versus SAM: Grand means of listening environment averaged across method of data collection.

Statistically significant differences were identified in listening environments of S+N, NA, Q+N, and L+N when compared to environments of Q, SA, and A+N. In environments S+N, NA, and L+N data was significantly less when compared to the non-significant environments of Q, SA, and A+N. In the Q+N environment the mean was significantly greater than the non-significant environments of Q, SA, and A+N. The interaction of listening environment and method of data collection for the Pre-questionnaire versus SAM condition is reported in Figure 8.

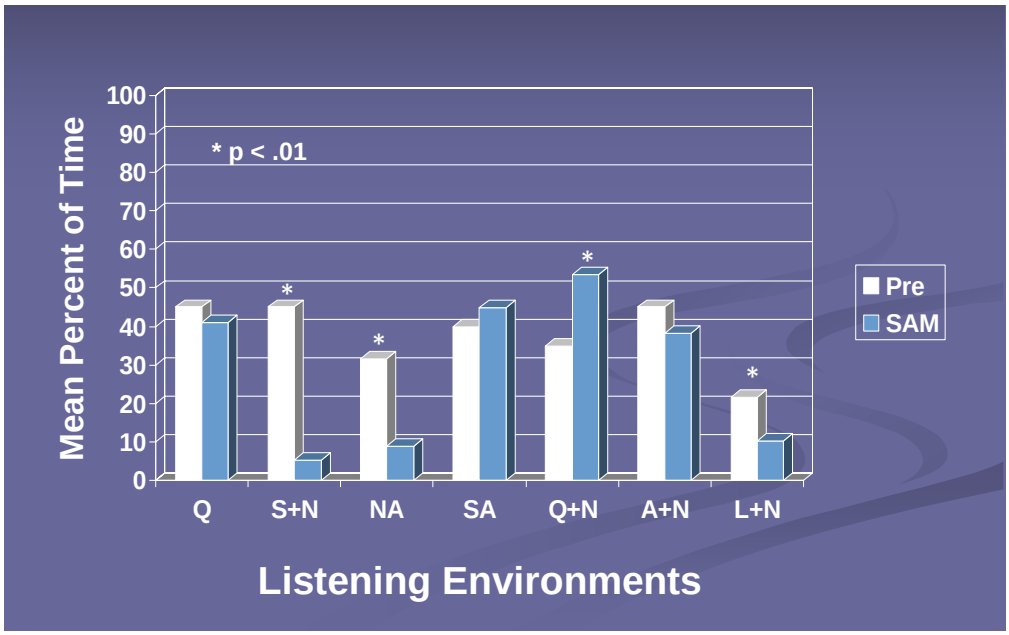

Figure 8. Interaction of method of data collection (Pre versus SAM) and listening environment.

Statistically significant differences are present (F= 22.5; dF = 6/84; $p < 0.001$). Post-hoc analysis using t-tests indicated significant differences ($p < 0.01$) were found in the interaction of method of data collection and listening environment. Listening environments that yielded the significant interaction included speech in noise (S+N), noise alone (NA), quiet input signal plus noise (Q+N) and loud input signal plus noise (L+N). In these listening environments statistically significant differences were found between the Pre-questionnaire data and the objective SAM measures. The percent of time spent in each listening environment reported by subjects was greater than the percent spent in environments of S+N, NA, and L+N, as reported by objective SAM data. That is, in these conditions subjects overestimated the time spent in the environment compared to mean SAM data. In the listening environment of Q+N, subjects reported significantly less percentage of time in the environment compared to the objective SAM data. That is, in the Q+N listening environment subjects underestimated the time spent in the environment compared to mean SAM data. The remaining listening environments of quiet (Q),

speech alone (SA), and average level input signal plus noise (A+N) did not yield significant interactions in method of data collection and listening environment. Audiologists presented with only the Pre-SAM questionnaire responses would identify the responses to include a need for directional microphone technology and/or hearing assistive technology. Based on the three of the listening environments indicating an overestimation of time spent in noise, directional microphone technology may not be required.

DISCUSSION

Results revealed statistically significant differences in the Pre-SAM questionnaire responses versus the SAM condition, and the Post-SAM questionnaire responses versus the SAM condition. These discrepancies identify specific listening environments in which subjects' perceptions were consistently inaccurate (S+N, NA, Q+N, and L+N) when compared to objective SAM data. An important consideration is to examine other discrepancies in subjective versus objective reports within the field of audiology as well as examining other professional disciplines.

Self-reported hearing aid use time has been used in the past to correlate the "success" of the hearing aid fitting (Ringdahl et al, 1994). Patient recollection of hearing aid use time may be misleading due to the inaccuracies demonstrated in self-report studies (Brooks, 1979; Haggard et al, 1981; Taubman et al, 1999). Some critics of self-report studies argue subjects may be influenced to respond "appropriately" not necessarily what may be most accurate (Torre et al, 2006).

The inaccuracies of self-reports are addressed in the following study regarding self-reports of hearing loss. Torre et al (2006) documented a study of older Latino-American adults' perception of their hearing loss. While the purpose of the study was to develop a screening tool

to use for elderly Spanish-speaking populations, the results provide some important implications on the subjects' ability to accurately report hearing loss. Subjects were interviewed with one question, "Do you feel you have hearing loss?" (translated in Spanish). Following the interview, an audiologic evaluation was completed to determine the presence of hearing loss. Results indicated 65% of subjects who reported normal hearing sensitivity actually had an audiometrically defined hearing loss (PTA at 500, 1000, 2000, and 4000 Hz greater than 25 dB HL). In addition, over 25% of the subjects who reported having a hearing loss did not have an audiometrically defined hearing loss. Authors acknowledged these overestimations of hearing loss could be due to the definition of hearing loss as stated in the project. For example, an individual with a high-frequency hearing loss could be noticing the effects of hearing impairment in difficult listening situations or could possibly be exhibiting symptoms of auditory processing disorder or other disorders while indicating audiometric thresholds within normal limits. Authors determined the sensitivity (probability of individuals with hearing loss to be correctly identified with hearing loss) and specificity (probability of individuals without hearing loss to be correctly identified as having no hearing loss) of the translated screening question to be 75.7% and 72.7%, respectively.

Research from other disciplines may indicate additional discrepancies between self-reports and actual events. A psychological study reviewed self-reports on smoking cessation, and some discrepancies exist between actual smoking activity and reported smoking activity. Subjects may be influenced to self-report towards social approval, especially on a topic as controversial as smoking (Crowne and Marlowe, 1964). Additional research from studies of weight management and self-reported physical activity indicate discrepancies between actual and self-reported physical activity. Klesges et al (1990) investigated the accuracy of reported

physical activity to observations from trained observers and physical trainers. Forty four subjects were included in the study to perform physical exercise for one hour and quantified the level of the activity. Unknown to the subjects, trained individuals observed the exercise and quantified the level of extraneous activity. These values were compared to the self-reported values of activity. Results indicated some accuracy to self-reported physical activity. Sedentary activity was underestimated in comparison to the exercise overestimates by over 300%. Additional research has reported a tendency for individuals to underestimate weight (Bowman and DeLucia, 1992). While the above-mentioned studies regarding weight management, physical activity, and smoking indicate grave discrepancies in actual and self-reported activities, it is unknown the level to which self-reported inaccuracies extend to other disciplines. Smoking, physical activity, and weight management may be held with a higher level of stigma rather than inaccurately reporting a variety of listening environments.

Results from the Pre versus SAM data indicate audiologists can not rely on patient recollection for accurate accounts of daily listening environments in environments of speech in noise, noise alone, a quiet level of input signal plus background noise, and a loud level of input noise plus background noise. These specific listening environments were overestimated and underestimated in the likely clinical situation (Pre versus SAM). Remember the Pre versus SAM condition identifies the process that occurs in a typical clinical situation: 1) audiologist inquires about the variety of listening demands, and 2) makes recommendations for hearing aid feature selection/activation to best suit individual communication demands. Audiologists do not typically have documented diversity of listening environments encountered by patients when selecting the most appropriate hearing aid features. Assuming the SAM data is truly representative of the diverse environments an individual encounters, the SAM permits the

audiologist to “follow” the patient for a specified time period and view data collected from every listening environment as well as the percent of time the subject was surrounded by varying input levels between soft (40 dB SPL) to loud (80 dB SPL). It is mentioned that the SAM data is assumed to be accurate, because no published data is available to indicate the accuracy of SAM measures to independent sources of measurement (e.g., dosimeter measures).

The post-hoc analysis of the Pre versus SAM data provides important implications as it is the most “typical” environment clinically for hearing aid selection to occur. Individual listening environments in this condition demonstrated variability between subjects as well as across subjects. Figures 9-15 in Appendix B illustrate individual responses for the Pre versus SAM data for each listening condition. For example, subject 13 (see Figures 9, 10, 11, and 14) demonstrated overestimations of the percentage of time in quiet, speech in noise, noise alone, and average input levels plus noise compared to SAM measures. However, subject 13 also demonstrated underestimations of the percentage of time in speech alone, quiet plus noise, and loud plus noise (see Figures 12, 13, and 15). Based on the subject’s responses it would be expected that the audiologist would use the patient’s report of spending most of the time quiet, and recommendations for hearing aid selection may have resulted in inappropriate hearing aid feature selection. This technology may not have used features to minimize noise levels to enhance speech and comfort in noise, such as adaptive directional microphones and noise reduction algorithms. The performance for this patient could be less than optimal in the difficult listening situations with inappropriately selected features. That is, select omnidirectional microphones when directional microphones would have been beneficial.

In a typical hearing aid evaluation, the audiologist makes recommendations for appropriate amplification based on patient’s seemingly accurate accounts of typical listening

environments, without the benefit of objective SAM measurements. Objective measurements before ordering hearing aids allow audiologists to better identify features that are essential for each individual's listening needs. The numerous feature selection options available in hearing aids with digital signal processing may be inappropriately chosen for some patients with severely inaccurate recollections. Counseling regarding realistic expectations may also be improved to address specific environments in which the hearing aids will function optimally **prior** to the hearing aid fitting. Providing patients with the most realistic expectations from the initial hearing aid evaluation will form a foundation of consistency as a reminder to individuals adjusting to new amplification or to those who have worn amplification before but are now adjusting to newer technology.

Statistically significant differences were also revealed in the Post-questionnaire versus SAM analysis in specific listening environments of S+N, NA, Q+N, and L+N (see Figure 16 in Appendix B). These results are similar to the Pre-questionnaire versus SAM condition in that subjects reported a greater amount of time spent in the S+N, NA, and L+N than the objective SAM measurements indicated. That is, subjects overestimated the time spent in those specific listening environments when compared to data collected from SAM. Subjects reported significantly less time spent in Q+N when compared to objective SAM measures, indicating the subjects underestimated the time spent in Q+N. The Post-questionnaire condition is not clinically relevant in that subjects were aware their listening environments had been measured for the previous three weeks when they were wearing SAM. This is not a "typical" clinical situation and did not warrant in-depth analysis in the current study to examine possible clinical implications.

When discussing the differences found in the Pre versus SAM condition and the Post versus SAM condition, it is important to consider the method in which SAM categorizes data into the four categories of quiet, speech only, speech in noise, and noise only. SAM will categorize sound into specific categories if it detects the level and spectra of the input signal required to designate a category. Specifically, the classification of speech only, speech in noise, and noise is based on whether or not the device would apply noise reduction if the device were a hearing aid. That is, the classification to include a situation with noise specifies the ***reaction*** of the device if it were to be implemented in a hearing aid, not necessarily the ***actual*** presence of the signal. There may be situations where noise is present with another input signal (i.e., speech), but if the SNR is not poor enough, the device will not apply noise reduction. That is, the situation may be categorized as "speech only" even though there is noise present, but not enough to justify the application of noise reduction.

The result of categorizing the signal based on the reaction of the SAM to the input could generate some discrepancies when applied to a comparison with the questionnaire. The questionnaire was directed to address subjects' perceptions of the presence of specific categories of sound (e.g., quiet, speech only, speech in noise, and noise only). However, based on the method in which SAM categorizes situations with noise, if SAM decides a signal with background noise is does not generate a poor enough SNR to apply noise reduction, the signal would be categorized without the "noise" specification. However, a subject may have perceived the background noise and chose to respond to the questionnaire accordingly. Therefore, a discrepancy between the questionnaire response and the objective SAM measurement has occurred. It is unknown how often this discrepancy occurred in the present study, but could

possibly account for some of the overestimations made by subjects in their responses in the statistically significant categories of S+N, NA, Q+N, and L+N.

The results between the two questionnaires (Pre versus Post) were not found to be significant in this study (see Figure 17 in Appendix B). Some possible explanations beyond true statistical insignificance may account for similar responses on both questionnaires. The questionnaire was constructed for the sole purpose of this study and was issued in a closed set format for efficiency and ease of subject response. Differences may have been noted if an open set response format was used to allow for a greater variability of responses. A closed set format with additional response options (the questionnaire had response choices of 0%, 25%, 50%, 75%, 100%) may have generated results with more variability between the pre-SAM and post-SAM conditions. SAM data was available in 1% increments compared to the 25% increments in the questionnaire responses. These differences could have led to varying results compared to an open set questionnaire.

Although the data collected by SAM can be helpful for decision-making regarding the technology and features of hearing aid selection, some improvements can be made for SAM. Five dropouts occurred in the study, and four of those were due to loss of the device. During the onset of the study, many subjects reported the device easily fell off the shirt/blouse. The fastener is a straight pin with no locking mechanism. Oticon was notified of the lost devices and the researcher was given permission to alter the pin to include a locking mechanism. Subjects reported the new pin was difficult to put on, but once in place it was secure in that position and did not fall off. After the pin change, no more SAMs were lost due to devices falling off shirts/blouses. Oticon should consider a permanent pin change to make the device less susceptible to loss.

The fifth device data was not available in the software because the device was programmed and read in separate NOAH files. While this is possible with hearing aids, the SAM chip does not allow for this flexibility and the data was corrupted. Subjects also reported through the study they were always unsure if the device was on and working properly. An on/off indicator light would help patients know if the device is functioning, and may also serve to help patients remember to remove the device from the shirt/blouse before clothes are laundered. Directional microphone technology is available in the SAM, but practical limitations due to the placement of the SAM on the lapel of the shirt did not make directional microphone technology useful at this time. This data could be better evaluated if the design included an ear level device for a "real-life" directional situation.

Measures made by SAM were assumed to be an accurate reflection of a patient's listening environments in the current study. No published data is available to demonstrate the validity of SAM measures compared to independent measures (i.e., dosimeter measurements). Due to the unknown validity of SAM measures it is impossible to determine the reliability and accuracy between devices. It is possible one SAM device was calibrated with a different sensitivity to noise compared to another SAM device. Differences in calibration would create different input levels and spectra to be placed in each category of quiet, speech in noise, speech only, or noise only. Variability in these measures would demonstrate discrepancies with the current study.

Assuming SAM measurements are accurately recording and categorizing listening environments, they can be valuable tools to assist audiologists in making informed decisions about the level of technology required for patient's "typical" listening environments. To be effective, design changes need to be incorporated to reduce likelihood of loss. At an invoice cost

of approximately $400 per device, these design changes are essential if SAM is to be incorporated into clinical practice by audiologists. For greater effectiveness of the SAM, the suggestions might be considered by Oticon in future versions of this device. Other manufacturers should consider the development and introduction of similar devices to assist audiologists in finding accurate information to base recommendations prior to ordering hearing aids.

Datalogging in hearing aids (versus datalogging available in SAM) provides information *after* the hearing aid fitting. Patient preferences can be assessed after the hearing aid fitting for fine tuning hearing aids to meet specific listening needs (Fabry, 2005). Past methods of systematic fine tuning have been established by methods using a flow chart system to address patient complaints or to use established recommendations from a panel of experts in the field (Jenstad et al, 2003; Kuk, 1999). Current datalogging systems provide information such as average volume adjustments, manual program changes, and total hours of hearing aid use time. Audiologists may view these results in manufacturers' software to provide fine tuning to meet individual listening needs. Table 2 (see Appendix C) provides detailed descriptions of the datalogging data provided by various hearing aid manufacturers and hearing aid models. Options available in datalogging are dictated by the level of technology as well as how recently the device has become commercially available.

The Phonak Extra is mid-level technology that has been available for many years. As indicated by Table 2, the Extra provides minimal datalogging information. The information is limited to generalized data regarding the number of volume control adjustments, program changes, and the total hours of use and average hours of use per day. More recent high-level technology including the Widex Inteo and Starkey Destiny provide detailed accounts of the

encountered listening environments. Inteo offers unique descriptions of specific listening environments, such as the time in a car, or office, or at home. Inteo also allows the patient to take a sample of a bothersome listening environment to provide the audiologist with the specific distressing environment for further fine tuning. It is important to note the datalogging in Inteo must be activated in the software as it is not the default setting. Other manufacturers include datalogging capabilities to be active in the default setting.

The Starkey Destiny includes two unique features when compared to other products. Average input level (re: dB SPL) is calculated to offer an average of each patient's listening level. This can be used in combination with patient accounts about the hearing aid experience to more appropriately fine tune. Suppose a patient is reporting the hearing aid is "too loud" and the average input level is high, the audiologist may choose to lower the SSPL90 for greater comfort in loud environments. Average battery life is also calculated after the patient has used four batteries. This may be beneficial to observe how changes in programming affect battery life. For example, changes in battery life can be observed by placing noise reduction at high compared to low. Many manufacturers offer suggestions for hearing aid adjustments based on environment measurements and manual volume control changes. The ReSound Metrix provides a weighted system to volume control changes made more recently compared to adjustments made during the adaptation period. The Metrix will log each time the patient decreases the volume and by how much, and will weight the changes more heavily for recent adjustments. The software will make programming changes based on these volume control adjustments.

Programming suggestions may offer audiologists an initial place for improving sound quality for patients. Automatic fine tuning guides do not readily offer explanations for gain, compression, and output changes to the frequency-response of the aids. It is difficult to view

modifications in these characteristics after the automatic fine tuning is complete compared to previous programming settings. It would be beneficial for manufacturers to delineate specific adjustments in gain, compression, and output based on the automatic fine tuning guides. A patient may report the hearing aid sounds "tinny." A fine tuning guide in the manufacturer's software may have a search box to type in the complaint or a series of drop-down menus to highlight the complaint. Terms such as "Do it" or "Apply Changes" may be used to make adjustments in real-time to minimize the problem. While these changes are time-efficient, it is difficult to visualize changes in characteristics of the hearing aid programming for specific frequencies and input levels, which may in turn create a different problem. Some manufacturers such as Phonak offer an "Undo" option to remove the changes if they are not successful, and return to the previous programming.

Datalogging information provided by hearing aids offers beneficial suggestions for the fine-tuning of hearing aids. Some of the data provided in SAM, are efficacious for the **pre-fit process** to indicate the importance of the level of technology. SAM may indicate a patient encounters environments with moderate to high levels of background noise could benefit from directional microphones or HAT (Hearing Assistive Technology). Descriptions obtained from datalogging in the pre-fit process may provide enhanced patient care to determine if premium level technology is necessary. Patients may not require high level technology (e.g., SAM reports a low occurrence of noise or complex input spectra. This may negate the need for noise reduction or directional microphones) that many hearing aid manufacturers provide. Minimizing the purchase of unnecessary technology may provide patients with an improved cost-analysis of their hearing aids. Kochkin (2003) reported a slight positive correlation between price and overall satisfactions with hearing aid benefit. However, negative correlations were observed between

price and perceptions of value, with value being defined as the performance relative to price. Lower prices of hearing aids may provide improved hearing to many users whose average acoustic environments do not necessitate premium technology. An improvement in cost-effectiveness may increase the value of hearing aids reported by patients.

CONCLUSIONS

Patient recollections in the pre-SAM and post-SAM questionnaires of daily listening environments are inaccurate when compared to objective measures made in SAM in specific environments of S+N, NA, Q+N, and L+N. SAM provides a solution to the inaccuracies of self-reports by providing audiologists the opportunity to "follow" a patient around a day, week, or longer. Oticon software allows a user-friendly view to counsel patients on the benefits of advanced technology such as adaptive directional microphones or flexible noise reduction capabilities. The sound level histogram in the manufacturer's software visualizes the complex components of multiple input levels and spectra of speech as well as background noise. The benefits of SAM can only be utilized if an improvement in the design is established to minimize loss of the device and data corruption. While the device is a cost to an audiology practice, the benefits of choosing appropriate amplification in later circumstances after the hearing aid fitting are considerable. Other manufacturers should consider developing similar devices and strategies for appropriate hearing aid selection.

This study encountered numerous difficulties on the programming and reading of the SAM device, as well as the occurrence of SAMs lost. Future research directions with SAM should account for these problems with extended time periods for data collections. Additional research designs should include a group of normal hearing listeners to determine if differences are present between hearing impaired perceptions of listening environments versus normal

hearing listening perceptions. Particularly in the listening environments which encountered the greatest overestimations and underestimations of discrepancies (S+N, NA, Q+N, and L+N). Future research designs should also include an open-set response format in the questionnaire. Significant results may be revealed between the two questionnaire conditions if greater response variability was available.

Appendix A

Listening Questionnaire
Washington University School of Medicine

Please carefully read each question before answering. If you have any questions about any of the items on this questionnaire please ask for clarification. It should take approximately 10 minutes to complete.

1. In the past 3 weeks, on average, what percentage of the time are you in a quiet/calm situation? For example, at home or in the office with no other people talking or background noise. Please circle your answer.

0% of the time **25% of the time** **50% of the time**
75% of the time **100% of the time**

2. In the past 3 weeks, on average, what percentage of the time are you in an environment with speech and background noise? For example, talking with a friend while walking in a store, outside, or a moderately noisy restaurant. Please circle your answer.

0% of the time **25% of the time** **50% of the time**

75% of the time **100% of the time**

3. In the past 3 weeks, on average, what percentage of the time are you in a very noisy environment? For example, a very loud restaurant, or using power tools, or driving with the windows down in your car? Please circle your answer.

0% of the time **25% of the time** **50% of the time**

75% of the time **100% of the time**

4. In the past 3 weeks, on average, what percentage of the time have you been in an environment while you were listening to speech alone? For example, visiting with one friend in a close proximity to one another. Please circle your answer.

0% of the time **25% of the time** **50% of the time**

75% of the time **100% of the time**

5. On average, what percentage of the time are you in a quiet environment where there is some background noise? For example, in an office/study with a fan turned on?

0% of the time **25% of the time** **50% of the time**

75% of the time **100% of the time**

6. On average, what percentage of the time are you in an average noisy environment with some background noise? For example, conversation in a car with traffic noise, or listening to the radio with the dishwasher running?

0% of the time **25% of the time** **50% of the time**

75% of the time **100% of the time**

7. On average what percentage of the time are you in a very loud environment with background noise? For example, on a busy street with a bus stopping at the curb?

0% of the time **25% of the time** **50% of the time**

75% of the time **100% of the time**

Appendix B

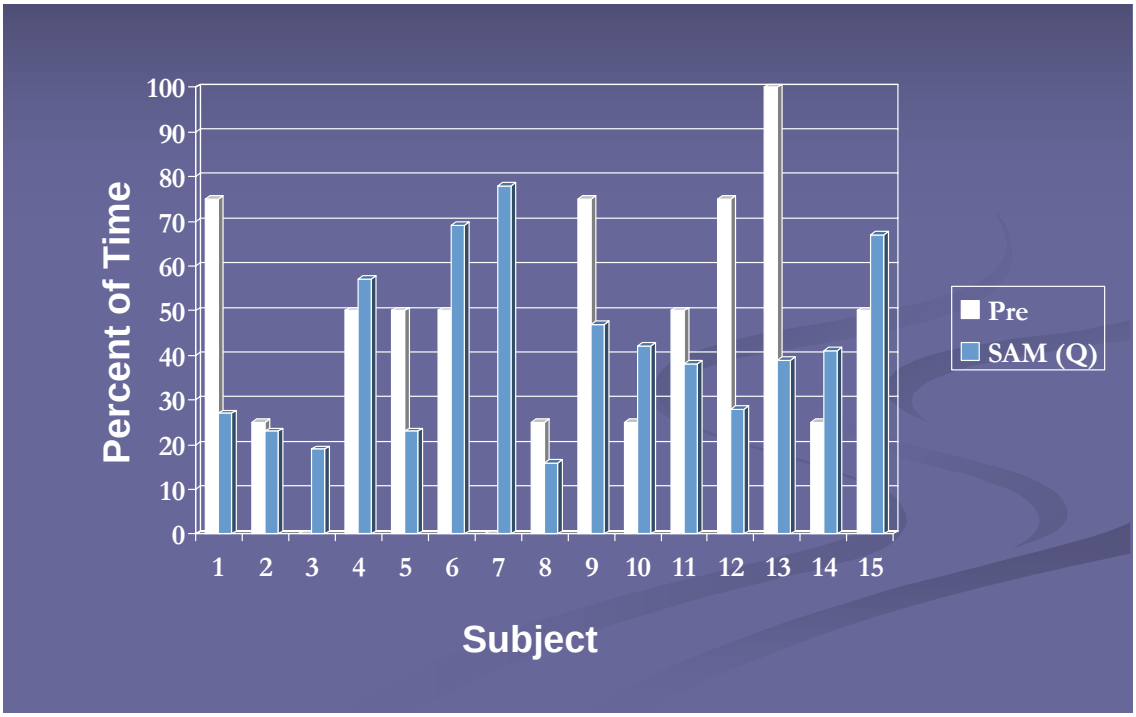

Figure 9. Pre versus SAM in quiet.

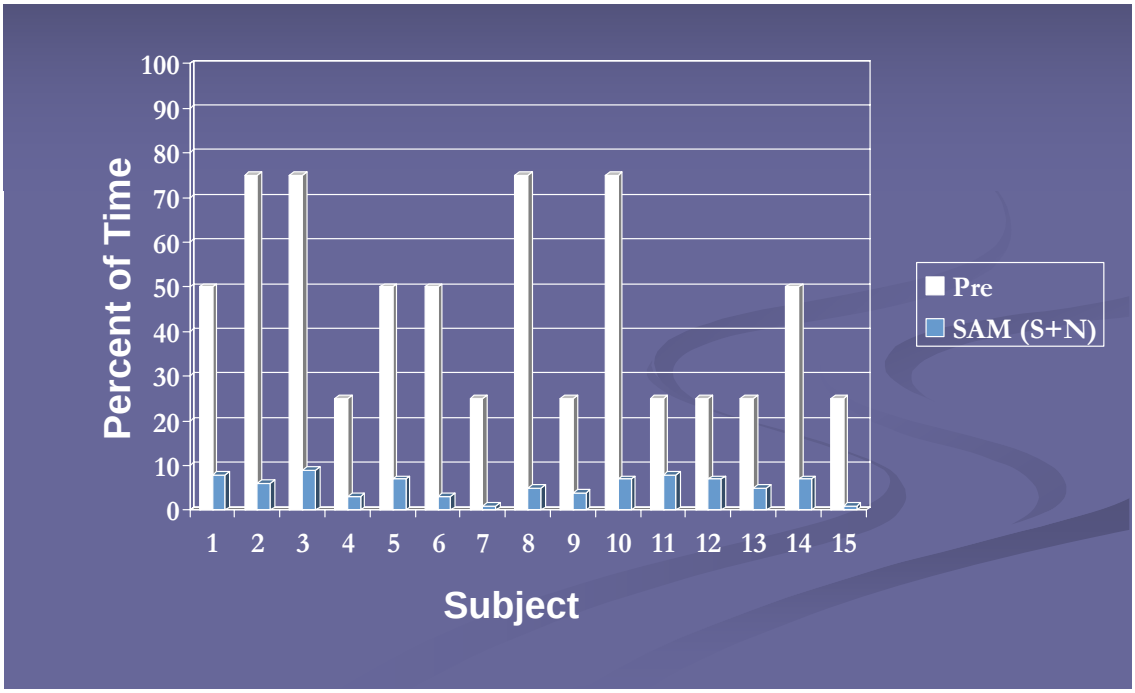

Figure 10. Pre versus SAM in speech + noise.

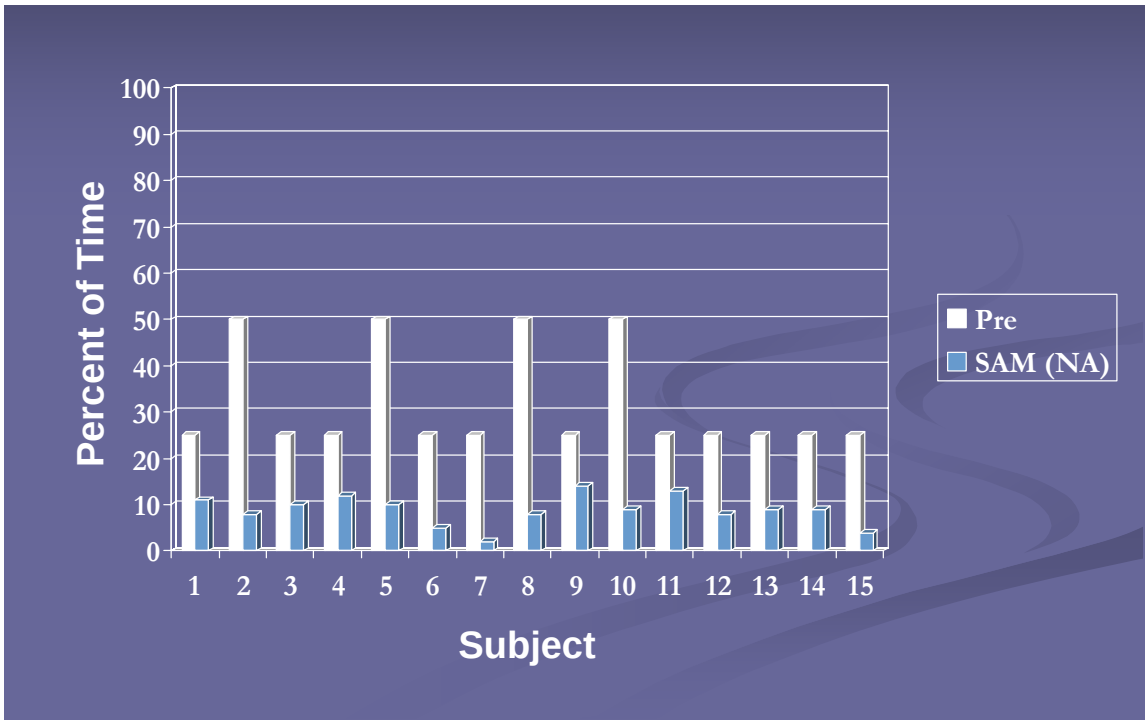

Figure 11. Pre versus SAM in noise alone.

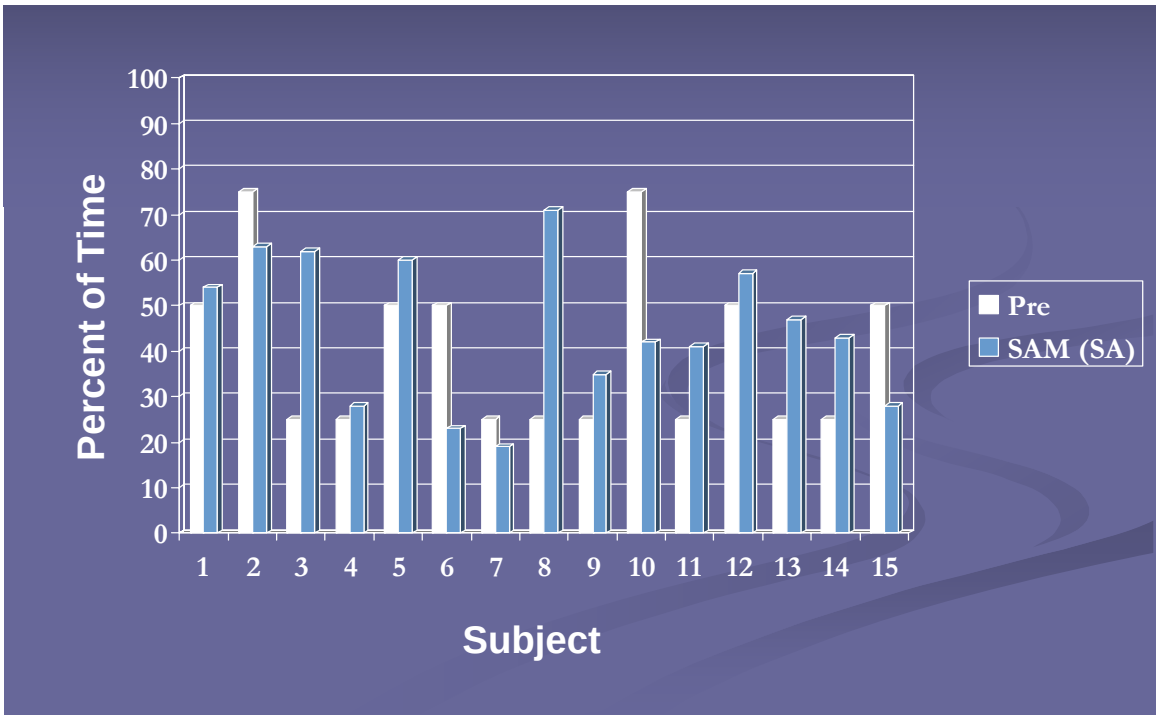

Figure 12. Pre versus SAM in speech alone.

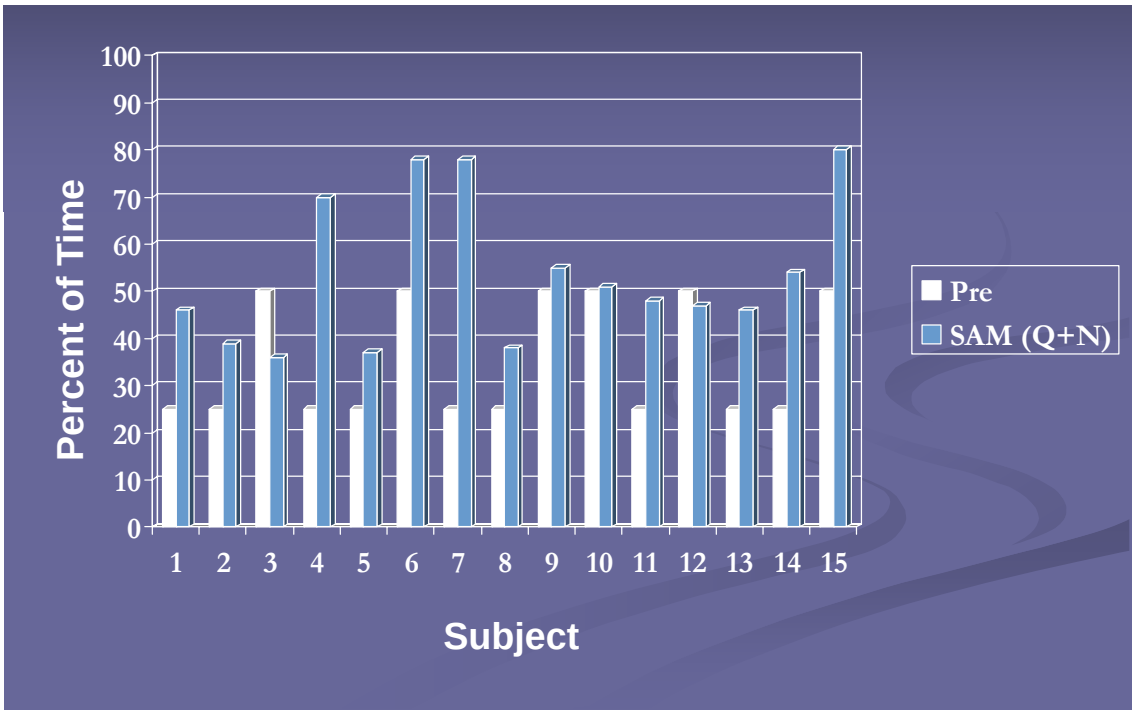

Figure 13. Pre versus SAM in quiet + noise.

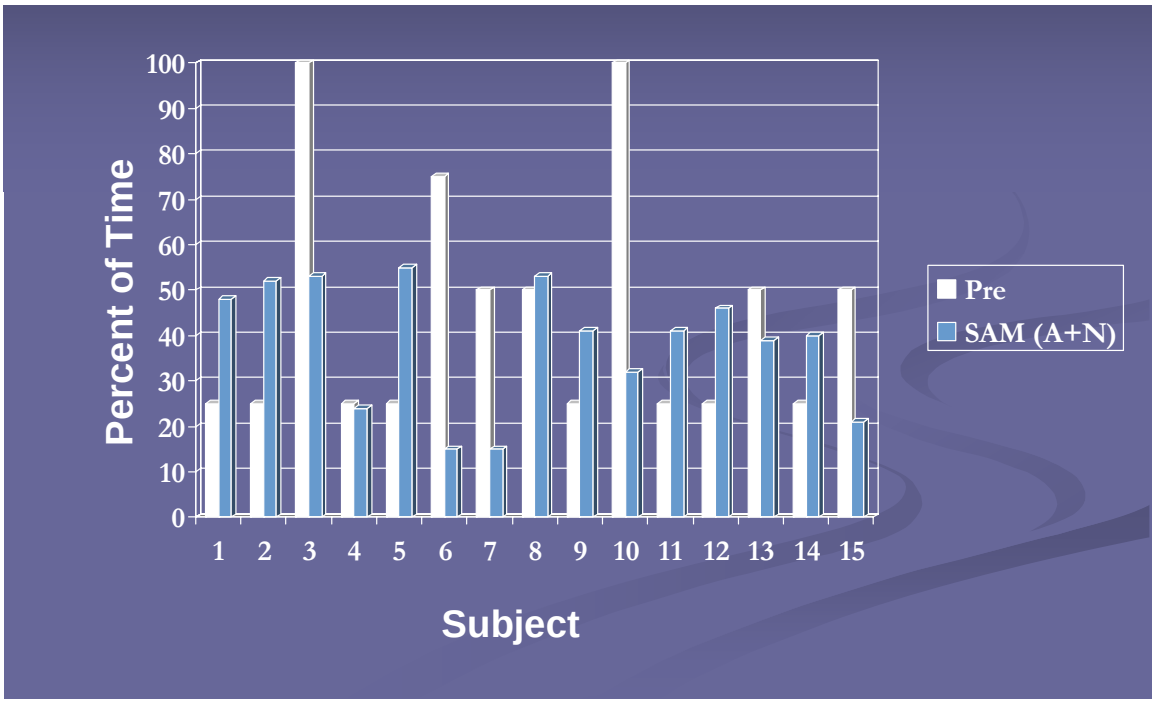

Figure 14. Pre versus SAM in average + noise.

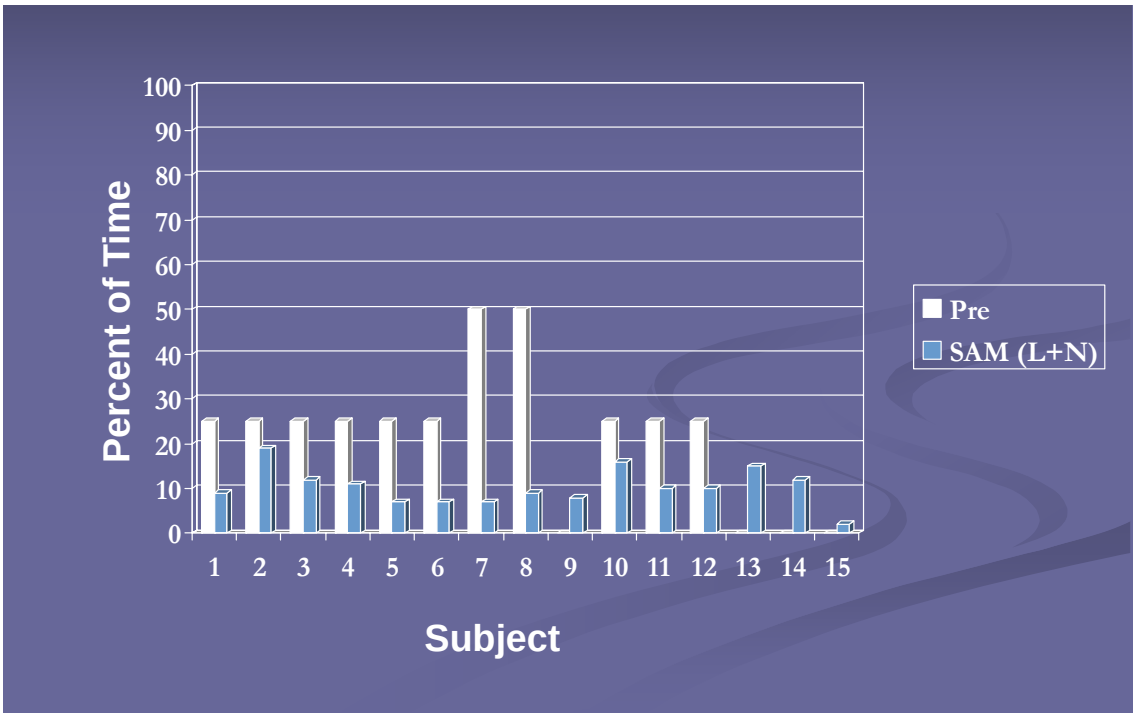

Figure 15. Pre versus SAM in loud + noise.

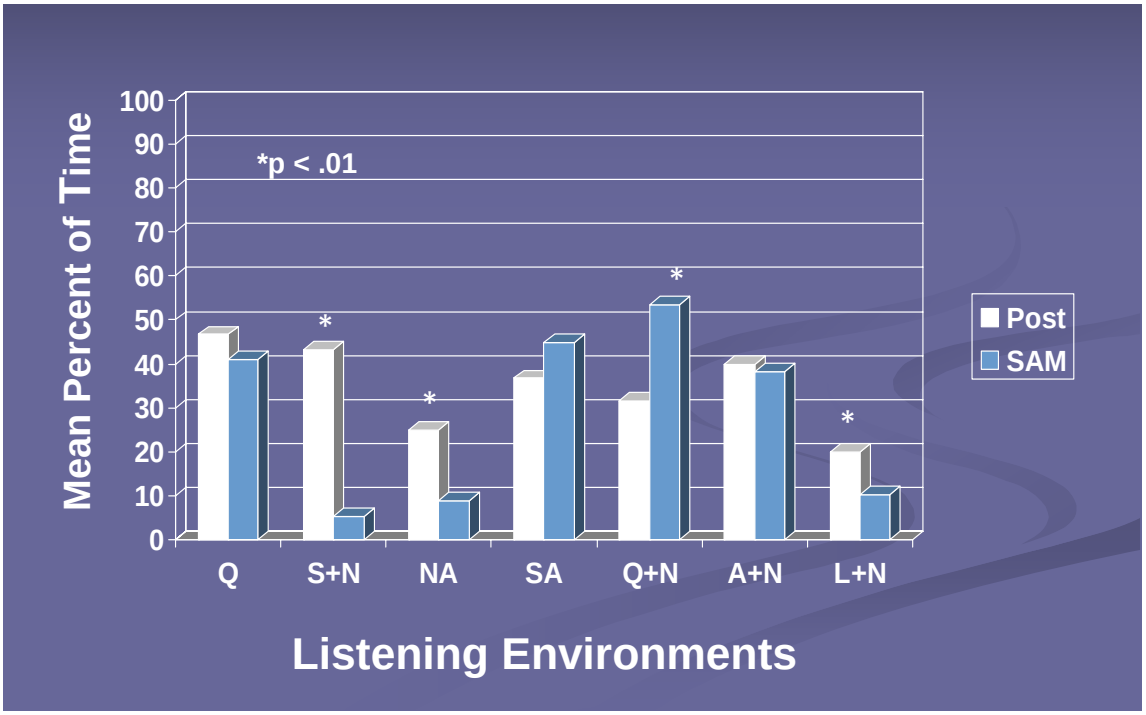

Figure 16. Post versus SAM

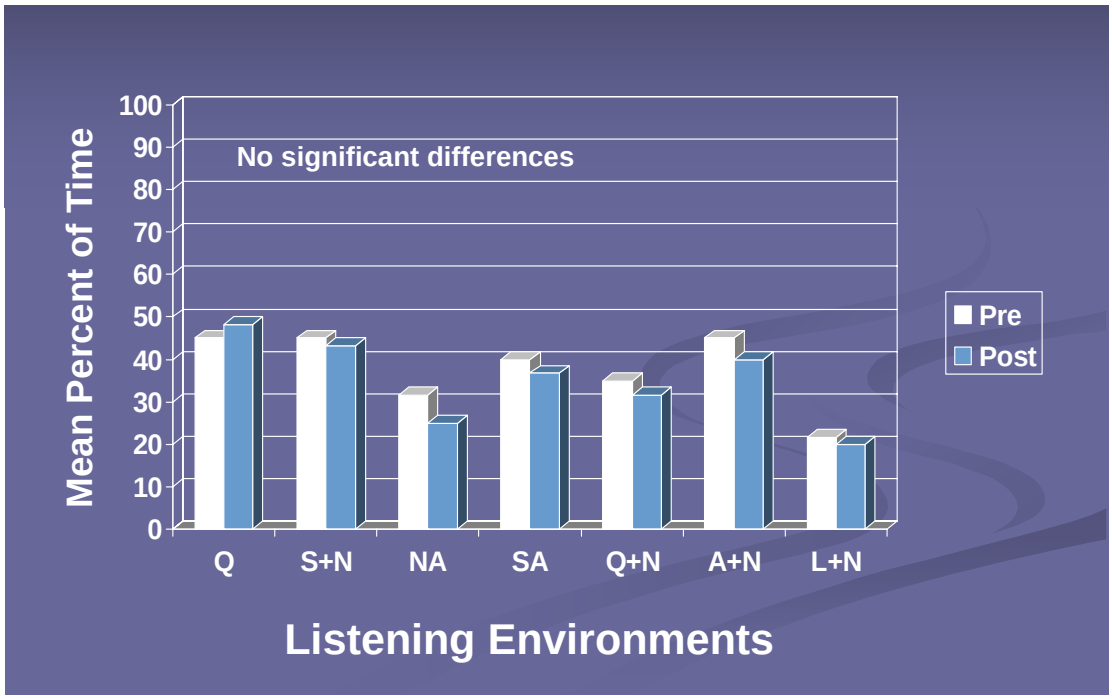

Figure 17. Pre versus Post

Appendix C

Table 2. Current datalogging features available in various technology levels and hearing aid manufacturers.

	ReSound	Oticon	Phonak			Starkey	Unitron		Widex
Feature	**Metrix**	**Delta**	**Savia**	**Eleva**	**Extra**	**Destiny**	**Indigo**	**Element**	**Inteo**
VC Adjustments:	X		X	X	X	X	X		X
Number of VC changes per environment	X								
VC changes per environment (dB SPL)	X		X	X					
VC changes per program- number of times per environment	X								
VC changes over time (minutes)	X								
Automatic Program Changes	X		X	X		X	X	X	
Manual Program Changes	X		X	X	X	X	X	X	X
Average Input level	X					X			
Average Battery Life						X			
Start/Stop Dates		X	X	X			X	X	X
Sound Level Measurements	X	X				X			X
% of Time in/using:									
Car/bus/train									X
Loud background noise									X
Noisy public place									X
At home/office									X
Quiet		X							X
Power tools/machinery									X
Moderately noisy place									X
At home/office with speech									X
Quiet place with speech									X
Other									X
Speech alone		X							

Noise alone		X							
Speech and noise		X							
Less than 40 dB SPL		X							
40-50 dB SPL		X							
50-60 dB SPL		X							
60-70 dB SPL		X							
70-80 dB SPL		X							
Greater than 80 dB SPL		X							
Directionality:									
% of time in directional (fixed, adaptive, etc.)		X	X	X		X	X	X	
% of time in omnidirectional		X	X	X		X	X	X	
Total Hours of Use:	X		X	X	X	X	X	X	X
Time per each use	X								
Use time per program	X								
Number of instrument uses	X								
Average hours of use/day	X	X	X	X	X	X	X	X	X
Recommendations for gain adjustments	X	X	X	X	X	X	X	X	X
Noise reduction adjustments			X	X		X			X

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