HEARING AID USAGE IN DIFFERENT LISTENING ENVIRONMENTS

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Abstract

This study investigates the listening environments of hearing aid users by employing the data logging capacity of their hearing aids. The idea that a hearing aid user's listening environments are important in prescribing desired hearing aid features has been discussed in the literature, however, investigation of listening environments has been limited in the past as it has relied mainly on subjective recordings. Data logging, the capacity of a hearing aid to continuously store information regarding time spent in different programs, listening environments, and microphone modes, is now available in a number of hearing aid models, and therefore provides an objective tool for studying a hearing aid user's listening environments. The data logging information from fifty-seven new hearing aid wearers, including 50 males and 7 females (mean age = 68 years, SD = 11.3), was obtained during the first routine clinic follow-up session for each individual. Measures of time spent in different listening environments, microphone modes, and overall sound levels, were analyzed. Hearing aid usage time was found to be highest in "Speech Only" situations (44.8%), followed by "Quiet" (26.7%), "Noise Only" (16.3%) and "Speech in Noise" (12.3%) situations. The majority of the hearing aid users' time was spent in "Surround" microphone mode (74.3%), followed in order by "Split" (22.3%) and "Full" (3.5%) directional modes. Results of two separate two-way ANOVAs revealed no significant age effect either on time spent in different listening environments [$F(3,49) = 0.7$, $p = 0.5$] or on time spent in different microphone modes [$F(3,20) = 0.6$, $p = 0.6$]. These findings provide empirical evidence regarding the general listening pattern of hearing aid users, which can be used as a starting point when troubleshooting problems experienced by hearing aid clients, or assessing a user's need for various hearing aid features.

1 Introduction

People generally participate in a variety of listening situations on a daily basis. All listening situations, including active and passive listening with different levels of background noise, pose challenges to people with hearing impairment, whose amplification needs may vary depending on the situation. To meet needs in different listening environments, most hearing aids provide two or more different listening programs, with a general listening program and various special programs prescribed for different listening situations involving noise, music, or telephone conversation. Therefore, hearing aid users often have the option to use a button or toggle on the hearing aid or on a remote control to select the desired program for the listening situation they are experiencing. Kates (1995) has identified a number of studies showing that hearing aid users preferred different hearing aid characteristics in different acoustic environments. In particular, a study by Ringdahl, Mangold and Lindkvist (1993) has demonstrated that despite the inconvenience of the button or toggle, hearing aid users would change the hearing aid program when faced with a change in the acoustic environment.

Hearing aids in recent development have become more automated, providing a general listening program that automatically changes its characteristics, such as directionality and noise management, depending on the acoustic environment. This move towards a single self-adjusting program for all situations creates a need for understanding the different listening environments that hearing aid users experience. To better understand an average hearing aid user's listening environments and thus to assist clinicians in making decisions about the use of various hearing aid features for individuals, this study investigates the general behaviour of hearing aid users with regard to their time spent in different listening environments. To clarify the current research progress on the topic of listening environments and highlight the importance of employing an objective instrumental tool for related research, the following subsections will review hearing aid studies on aspects related a hearing aid user's listening environments, including microphone modes, sound level, and environment classification, and describe the hearing aid feature of data logging, which will be used in this study to monitor the listening pattern of hearing aid users.

1.1 Listening Environments

The importance of understanding a hearing aid user's listening environments in prescribing desired hearing aid features has been discussed in the literature since the late twentieth century. Gatehouse et al. (1999; 2006a; 2006b) coined the term "auditory ecology", which refers to the auditory environments people are faced with and the subjective importance assigned to these environments. Jensen and Nielsen (2005) asked 18 experienced hearing aid users to make short sound recordings of their daily listening situations on small portable recorders in order to investigate their auditory ecology. The participants were aged between 39 and 72 years, with a mean age of 58 years, and on average had moderate, sloping sensorineural hearing losses. Each sound recording was classified by the participant into one of seven categories on a questionnaire: “conversation with several persons”, “conversation with one person”, “other people’s speech or conversation”, “TV/Radio-informative programs”, “everyday sounds”, “music”, and “other”. Results from Jensen and Nielsen’s (2005) study showed that approximately 60% of the recordings were categorised as being a situation involving the understanding of speech. As this was a study of auditory ecology, which involves the importance of each situation to the user as well as the acoustic characteristics of the corresponding listening environment, the authors also examined the importance rating of each listening situation using a questionnaire, with a rating scale of zero to ten, where zero indicated the situation was of “little” importance and ten indicated the situation had “a lot” of importance to the participant. As the mean scores of the importance ratings for the seven categories were all found to be high, the researchers concluded that the ability to hear is important to users in a variety of situations. However, the analysis of the distribution of these categories of listening situations was complicated by the fact that not all the participants created sound recordings from every category. In addition, the study examined only those acoustic environments that the participants chose to record, rather than all the acoustic environments of their daily life while wearing hearing aids. These limitations were obviously related to the method used for data collection. An investigation of all the listening environments of hearing aid users, not biased by what participants choose to record, is needed to reflect more reliably the distribution of a hearing-aid user's daily listening situations.

Another example of inconclusive findings regarding the pattern of time spent in different listening environments is a study by Walden, Surr, Cord, and Dyrlund (2004), who examined the listening environments of 17 hearing impaired adults, with a mean age of 70.8 years, by asking the participants to make diary entries of every active listening situation they encountered over a seven day period. The diary entries included the location, the size of the location, the presence or absence of carpeting, the location of and distance from the primary talker/sound source, and the presence or absence and location of background noise. The two most frequently occurring situations, which accounted for 36.6% of total active listening situations, were found to share the characteristics of the presence of background noise and a primary signal source in "front" of and "near" to the listener. The next two most frequently occurring situations, accounting for 26.8% of active listening situations, also involved a primary signal source in "front" of and "near" to the listener but in the absence of background noise. The authors noted that these situations, although occurring most frequently, were not necessarily those in which the most time was spent. None of the four situations which ranked highly in frequency of occurrence were in the top five rankings of average time spent in the situations based on the participants' self reports. However, when frequency of occurrence was multiplied by time spent, indicating an overall importance score for each situation, those four situations again exhibited the highest rankings. The data for the average time spent in each situation showed that the participants rarely reported listening situations lasting less than a few minutes, which was undoubtedly due to the manual diary reporting system used. These unreported brief encounters may nevertheless represent situations with important communications needs for the hearing aid user, and an investigation of all listening environments, no matter how brief, would improve understanding of daily listening situations. Therefore, an objective and automated environment and time tracking device is needed to monitor the listening pattern of a hearing aid user with greater precision and reliability.

1.1.1 Microphone Mode

The pattern of hearing aid usage can be examined not only in terms of time spent in different listening environments, but also in relation to the selection of microphone mode. Many of the listening environments encountered in everyday life include some form of background noise that can interfere with the signal one intends to hear. Persons with hearing impairment, even when wearing hearing aids, reportedly have greater difficulty listening to speech in the presence of background noise, such as the babble of speech from other party-goers or in a crowded supermarket. This background noise problem has been helped to some extent by the introduction of directional microphones (Bentler, 2005; Bentler, Palmer, & Mueller, 2006; Ricketts & Dittberner, 2002). Based on the notion that the desired signal is usually in front of the listener, fixed directional microphones in hearing aids are designed so that sensitivity to sound coming from directions other than the front is reduced, as opposed to an omnidirectional microphone mode, which allows sound energy to be picked up equally from all directions (Dillon, 2001). The pattern of sensitivity of the directional microphone to sounds coming from different directions is known as the directivity pattern. Adaptive directional microphones respond to the environment by continually adjusting their directivity pattern, directing the null towards the main noise source.

There has been some investigation into hearing aid usage patterns in terms of microphone mode use. Walden et al. (2004) investigated the listening environments and preferred microphone modes of 17 hearing impaired participants. The participants were required to record their active listening situations as outlined above. They were also asked to note which listening program they preferred for each situation, where programs 1 and 2 of their hearing aids had been randomly assigned an omnidirectional or directional microphone mode. Overall, the data showed that a directional mode will only be preferred in certain listening environments, specifically, in the presence of background noise and with the primary signal source located in "front" of and "near" to the listener. However, as noted above, these situations were found in this study to make up 36.6% of total active listening situations, and 31.8% of total active listening time. As hearing aids can now change the microphone mode based on the acoustic environment automatically without the hearing aid user having to instigate a manual change, information about the time spent in different microphone modes when in this automatic mode would be an interesting comparison to findings of Walden et al.'s (2004) study, where only manual control of the microphone mode was available.

1.1.2 Sound Level

Another factor related to listening environments is the overall sound level of the input to the hearing aid. As situations with a high level of background noise tend to be the most difficult listening environments, the overall sound level of the input to the hearing aid needs to be taken into consideration when investigating a hearing aid user's listening pattern. Jensen and Nielsen (2005), whose study has been outlined above, evaluated the mean RMS levels in dB SPL of the sound recordings from each of the seven listening environment categories studied. The authors found that the average sound levels for each of the categories were similar and attributed this finding to the observation that each category covered many different acoustic environments. Consequently, the average sound levels were evaluated based on the location of the recording rather than on the category. The average sound levels were shown to be much more varied between locations than between categories. It was found that the two locations with the highest mean RMS were in the car and on the bus. The authors noted that participants made recordings pertaining to all seven listening environment categories while in the car, indicating that cars may present many different listening situations that can be particularly challenging due to the relatively high level of background noise from the engine. However, as previously mentioned, the overall sound pressure level was studied by Jensen and Nielsen (2005) only for environments the participants chose to record. Information about the sound levels of all environments experienced by hearing aid users are needed to improve understanding of a hearing aid user’s daily listening situations.

1.1.3 Environment Classification

In order to investigate the listening environments of hearing aid users a method for classifying those acoustic environments is needed. Büchler, Allegro, Launer, and Dillier (2005) outlined several possibilities for sound classification that are used in hearing aids mainly for noise management. These included algorithms involving amplitude statistics, modulation frequency analysis, temporal level fluctuations and spectral shape, or linear prediction coefficients. These systems aim to separate clean speech signals from noise. More generally, the hearing aid system uses some number of acoustic features (such as amplitude modulations, frequency modulations, or tonality) from the incoming signal to classify the acoustic environment and make decisions about the best response to that environment. The capacity of monitoring aspects of the sound environments of the hearing aid user has become part of an integrated hearing aid feature called data logging, which allows for automated tracking of listening environments.

1.2 Data Logging

Data logging is the automatic recording of hearing aid use by the hearing aids themselves. This feature aims to monitor individual listening behaviours so that the information provided may be useful to audiologists in troubleshooting problems or making fine-tuning decisions during hearing aid adjustments. The technology has been available since 1989, when the 3M MemoryMate hearing aid was introduced. The simple data logging available in this hearing aid consisted of hours of use and listening program changes. More sophisticated data logging has only been available since early 2005. Given the very recent introduction of this hearing aid feature, little research has been completed using the feature as an objective instrument to examine general hearing aid user behaviour. However, some initial studies have shown that the objective nature of the data logging instrument was a valuable tool in research (for example, Mangold, Ringdahl & Eriksson-Mangold, 1993). It is most likely that data logging, with the capacity to track environments and various types of usage information in a continuous manner, would be useful in monitoring the listening pattern of a hearing aid user with greater precision than has been possible in the past. Common data logging features and their usage in clinical and research applications will be described in this section.

1.2.1 Data Logging features

The currently available data logging feature records a number of behaviours related to hearing aid use. The behaviours recorded include variables such as hours of hearing aid use, manual volume control changes, time spent using different listening programs, which may include general listening programs, music programs, and telephone programs, and time spent in different listening situations, such as quiet or speech in noise. Hours of use, which is often reported as an average daily figure, is the length of time for which each hearing aid is switched on. Usage time may be broken down into hours spent using each of the listening programs incorporated in the hearing aid. The time spent in different listening situations is also recorded. The hearing aid recognises whether a listening situation falls into a certain category and calculates the relative percentage of time or hours spent in each situation. If a hearing aid is fitted with a volume control, the data logging feature also records the changes the user makes, such as the average upward deviation from the default setting. These parameters are displayed in chart or tabular form when the hearing aids are connected to a computer installed with the hearing aid manufacturer's fitting software. Figures 1 and 2 are samples of the representative displays of the data logging feature of two hearing aids. Table 1 presents common data logging features available in hearing aids produced by five major hearing aid manufacturers.

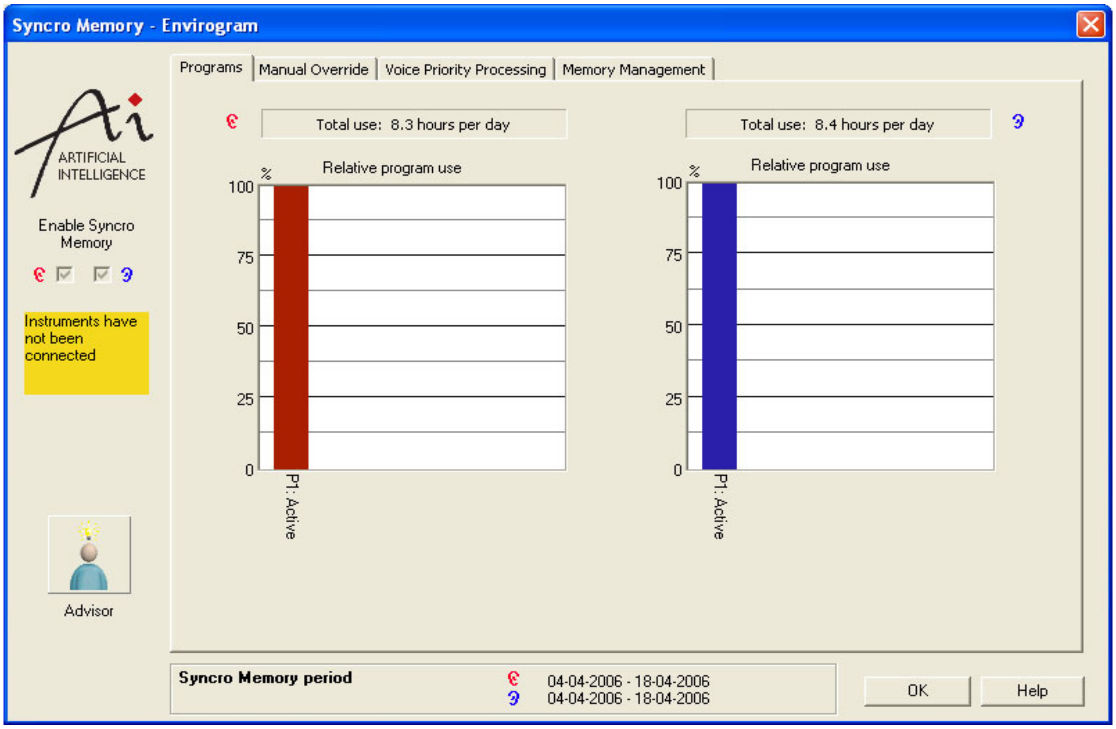

Figure 1. Oticon Syncro Memory display example showing average use per day in hours and relative program use.

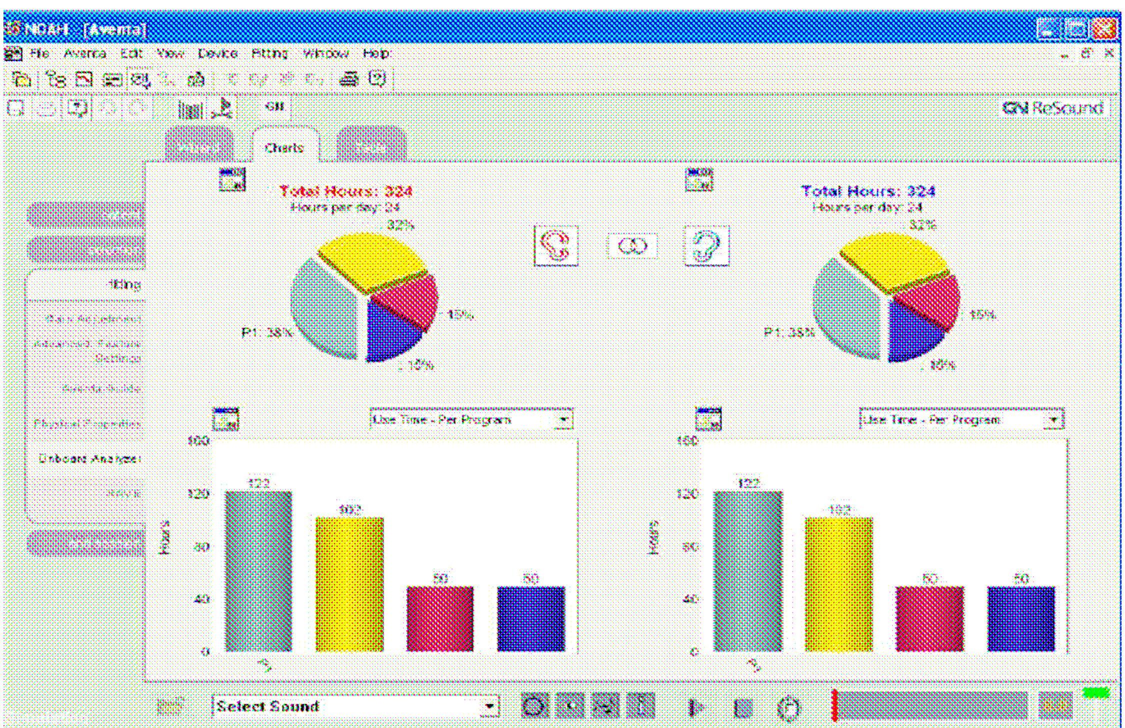

Figure 2. GN ReSound Metrix Onboard Analyzer display example showing total hours of use, total hours of use per program, average use per day in hours, and relative program use.

Table 1. Common data logging features of hearing aids from five major hearing aid manufacturers.

Feature	GN ReSound Metrix	Oticon Syncro	Siemens Centra	Widex Inteo	Phonak Savia
Usage Time	Total Use in Hours		Total Use in Hours	Total Use in Hours	Total Use in Hours
	Average Use per Day in Hours	Average Use per Day in Hours	Average Use per Day in Hours	Average Use per Day in Hours	Average Use per Day in Hours
Program Usage	Use per Program in Hours	Relative Program Use in Percent	Relative Program Use in Percent	Relative Program Use in Percent	Relative Program Use in Percent
		Average Use per Program per Day in Hours			
Listening Situations	Use Time per Environment in Hours	Relative Use Time per Environment in Percent	Relative Use Time per Environment in Percent	Relative Use Time per Environment in Percent	Relative Use Time per Environment in Percent

1.2.2 Clinical Application

The logged data from each hearing aid can be retrieved via the hearing aid manufacturer's fitting software, which includes a guide on how to interpret it. The recorded usage time, for example, might be examined by the audiologist after a client complains of short battery life. A high average measure of hours of use per day shown in the logged data suggests the client may have left the hearing aid on when not in use, resulting in short battery life (Groth & Nelson, 2005). In a case where a hearing aid user is regularly turning up their volume control, an increase in gain might be suggested. The parameter of usage time in different listening environments may be used to demonstrate to a client the appropriateness of certain features, such as noise cancellation, or to assist in choosing the technology most suitable to a client's typical listening situations (Flynn, 2005b).

Data logging has been shown to allow for evaluation of hearing aid use in a population who may not give reliable verbal information. In a study assessing the benefit of multiple programs in hearing aids, Mangold, Ringdahl and Eriksson-Mangold (1993) observed the pattern of hearing aid usage in six children aged between 9 and sixteen years of age, and compared information from data logging with that from diary entries and from interviews with the children and their parents and teachers. Based on the finding that the data logging feature allowed the researchers to identify equipment or programming failures, asymmetrical hearing aid use, and the lack of use of a listening program, Mangold et al. (1993) concluded that the data logging capability of the hearing aids provided clinicians with valuable information about the benefit the children were receiving from their hearing aids, as well as that data logging "provides a unique tool for conducting clinical studies of the utilisation of hearing aids" (p. 451).

Data logging appears most helpful when the reliability of subjective information is questioned. For example, although it is understandable that a child may not give reliable verbal information on hearing aid use, one might ask why the clinician could not simply ask an adult client about the different aspects of their listening behaviour. However, studies have shown that adults' subjective descriptions of hearing aid use time may be misleading (Maki-Torkko, Sorri, & Laukli, 2001; Taubman, Palmer, Durrant, & Pratt, 1999) and more complex descriptions of daily listening situations or volume control use are likely to be uncertain. In addition, a client may tend to report satisfaction with the hearing aids and only report a problem after being presented with specific information from the data logging. Therefore, while data logging gives objective data, further questioning of the client will often be required to confirm or elaborate on the information the data logging is presenting (Flynn, 2005a). Another example showing the usefulness of data logging information was provided by Groth and Nelson (2005) in describing a client who reported being happy with the hearing aids while examination of the data logging information showed a large discrepancy in use time between the left and right hearing aids. After further questioning, the client reported that his own voice sounded strange and that he had itchy ears so he always took one aid out after work. The client thought this discomfort was something to which he must become accustomed, whereas a later change to an open fitting hearing aid resolved the problem. Therefore, hearing aid manufacturers suggest the data logging feature may act as an objective starting point to investigate a hearing aid user's subjective experiences.

1.2.3 Research Applications

Data logging has also been used as a support tool in clinical studies of multi-programmable hearing aids to observe usage patterns of the multiple programs. For example, Mangold, Eriksson-Mangold, Israelsson, Leijon, and Ringdahl (1990) conducted a clinical study of the multi-programmable 3M MemoryMate hearing aid to investigate whether participants took advantage of the different programs and included observations of the utility of the hearing aid's data logging feature. In the study, the participants' usage of eight available programmes was tracked with the data logging device. The simple log reported number of uses of each program, total use time of each program, total on time of the hearing aid, and number of switches between programs. Participants were five men and nine women with slight to moderate sensorineural hearing loss. These participants were aged between 51 and 76 years and the number of years of previous hearing aid use had a median of 1.5 years (range: 0.5 to 25 years). Mangold et al. (1990) observed that data logging was a useful tool for reprogramming the MemoryMate aid and commented that the data logging capability of MemoryMate would also make it a valuable research instrument for studying hearing aid usage.

Similarly, Ringdahl, Eriksson-Mangold, Israelsson, Lindkvist, and Mangold (1990) carried out a clinical trial of the same programmable hearing aid to investigate the need to employ different programs for different listening environments. The participants were 22 experienced hearing aid users aged between 22 and 77 years. Ringdahl et al. (1990) found that there was substantial variation in total use time between subjects. They suggested that subjective judgements of usage employed in the study had questionable reliability for those participants with low total use time and thus data logging "in the future might have importance for fitting of the programmable hearing aid, as well as for future research programmes" (p. 241). Although the basic form of the data logging available in the 3M MemoryMate hearing instrument limited its research application, as information on listening environments was not available, Ringdahl et al.'s (1990) study highlighted the advantages of using information obtained from data logging, particularly when there is a low total use time, in understanding hearing aid usage patterns.

In studies with both subjective and objective evaluation of hearing aid usage, information from data logging has been used to exclude participants who did not use the hearing aid or programs for a sufficient amount of time so that the validity of the observations made based on the questionnaires participants filled out could be strengthened. For example, Ringdahl, Mangold, and Lindkvist (1993) extended their earlier work (Ringdahl et al., 1990) to examine whether hearing aid users used the different programs available in acoustically varying listening environments and chose a specific program for certain environments. Subsequently, Ringdahl (1994) combined the results of earlier studies on data logging to investigate whether hearing aid users took advantage of different programs and used their hearing aid in acoustically variable environments. Both of these studies used data logging to support the data that was obtained subjectively from participants to aid their evaluations. Nevertheless, these studies still relied on participant report for information regarding listening environments as the hearing aid was not yet capable of identifying such complex information.

Humes, Halling, and Coughlin (1996) used data logging as an objective measure of hearing aid use in evaluating the reliability and stability of hearing aid outcome measures. Twenty participants aged 63 to 78 years were tested on a variety of outcome measures at 0, 7, 15, 30, 60, 90, and 180 days post-fitting of their hearing aids. One of those hearing aid outcome measures was estimates of daily use, recorded subjectively by participant report, and objectively with the data logging capability of the hearing aids. The authors found that mean measures of hearing aid use from the data logging feature were fairly stable over time up to the 90 days post-fit interval (the data logging capacity did not allow for usage estimates at 180 days post-fit). There was an increase in hearing aid use at the 15 day interval, but no significant post-fit interval effect when the data at the 15 day interval was removed. The authors also examined the stability of daily use on an individual basis and found moderate to strong test-retest correlations for the majority of individuals. Humes et al. (1996) concluded that the recording of hours of use by the data logging capability of hearing aids is a stable hearing aid outcome measure, particularly when obtained more than 15 days post-fit. This finding helps justify the use of data logging in this study, at least the parameter of hours of use, in the current study which will examine hearing aid usage information from within the 90 day post-fit period.

1.4 Summary

Listening environments, while acknowledged as being important to the prescribing of hearing aid features, have had little coverage in the literature. Most studies related to the listening environments of hearing aid users used diary or questionnaire based formats that require the participants to choose situations to report and thus have selection bias that might limit the interpretation of the result. Since the hearing aid feature of data logging has the advantage of yielding continuous objective measures of aspects of the users' listening environments and has been shown in earlier studies to be a reliable instrument in tracking behaviours of hearing aid usage, this study employs data logging to examine the listening environments of adult hearing aid users. The main research question for this study is: What is the general behaviour of the hearing aid user in regard to time spent in different listening environments? More specifically, the distribution of time spent in relation to environmental classification, microphone mode, and overall sound levels will be investigated.

2 Method

To investigate the general behaviour of hearing aid users in regards to time spent in different listening environments, this study employed the data logging capability of two currently available hearing aids as an objective tool. The following subsections will describe participants, instrumentation, procedure, and methods used for data measurement and statistical analysis in this study.

2.1 Participants

Fifty-seven hearing aid wearers were recruited from two private Audiology clinics in Christchurch, New Zealand. The subject inclusion criterion was adult hearing aid users who have been fitted with either Oticon Syncro or GN ReSound Metrix hearing aids and whose data logging information could be retrieved from the clinic database. A consecutive convenience sampling method was used to include hearing aid users who were fitted with their hearing aids between June 2005 and August 2006 in the two chosen clinics. Eighty potential participants were identified in the clinical database. These clients were sent an information sheet and consent form as approved by the institutional ethical review board and asked to return the signed consent forms in a pre-paid envelope. Out of a total of fifty-nine clients who returned the consent form, fifty-seven clients agreed to participate in the study. Participants were 50 males and 7 females with a mean age of 68.0 years (SD = 11.32). The average hearing losses for each ear are shown in Figure 3. The hearing loss of all participants was found to be sensorineural in nature, except for three participants with mixed losses. Twenty-eight of the participants wore Syncro hearing aids and the remaining twenty-nine participants wore Metrix hearing aids. All fittings were binaural. Twenty-six (45.6%) of the participants wore behind-the-ear (BTE) aids, 15 (26.3%) wore in-the-canal (ITC), 14 (24.6%) wore in-the-ear (ITE), one (1.8%) wore completely-in-the-canal (CIC), and one wore a BTE for the right ear and an ITE for the left ear.

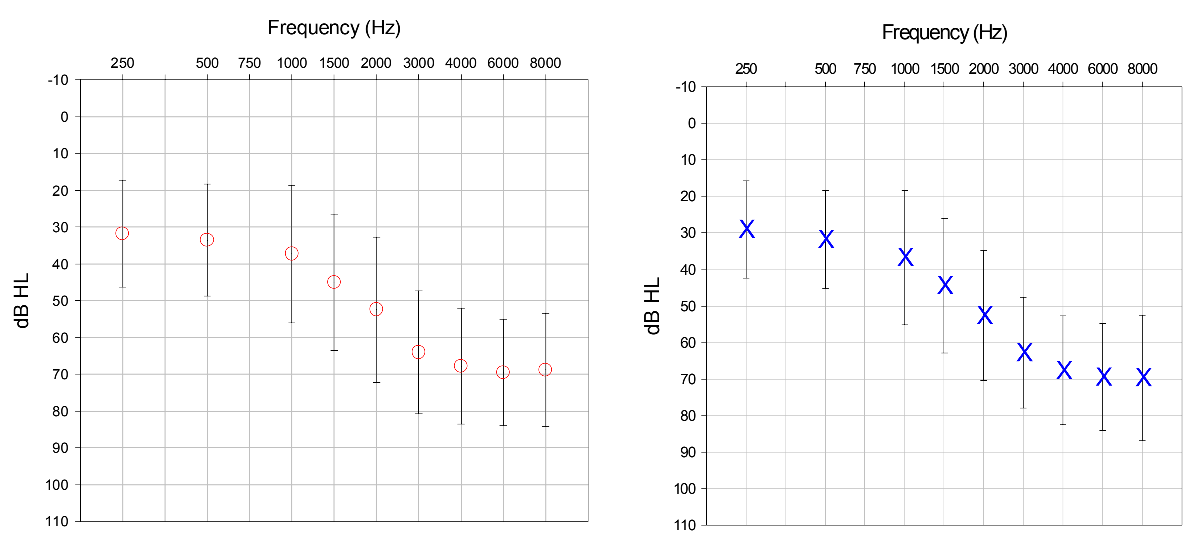

Figure 3. Average audiometric thresholds of the participants.

2.2 Instrumentation

2.2.1 Hearing Aids

The two hearing aids used in this study were the GN ReSound Metrix (Metrix) and the Oticon Syncro (Syncro). The Metrix is a 17-channel, dual-microphone instrument and the Syncro is an 8-channel, dual-microphone instrument, both with adaptive directionality. Both instruments have up to four customisable listening programs in all styles except for CIC style, which allows for only one program. Both the Metrix and the Syncro are in the most expensive price-range of hearing instruments due to their relatively numerous and sophisticated features and are often reserved for clients who frequently experience difficult listening environments.

2.2.2 Data logging Software

The Syncro uses the Syncro Memory™ feature in the Oticon Genie 7.0 software to display the data logging information. The data logging information accessible for the Syncro is summarized in Table 2. The volume control, microphone mode, and listening environment information is available for each listening program. The Syncro software also offers a graphical representation of the distribution of overall sound level in dB SPL which is coined an “envirogram”. An example of an envirogram is shown in Figure 4. As shown in Figure 4, the envirogram is also broken down into the four environmental classifications, i.e. “Quiet”, “Speech Only”, “Speech in Noise”, and “Noise Only”. The three microphone modes of the Oticon Syncro include “Surround”, “Split directional”, and “Full directional”. Surround mode is an omni-directional mode. Split directional mode is where the surround mode is used in the low frequency band, but full directionality is used in the remaining three high frequency bands. Full directional mode uses full directionality in all four of the frequency bands (Flynn, 2004). The Metrix uses the Onboard Analyzer™ feature in the GN ReSound Aventa 2.0 software and offers a similar array of information for each ear, as displayed in Table 3.

Table 2. Data logging information accessible for Oticon Syncro.

Data Logged	Situations	Units
Average Total Usage		Hours per day
Relative Program Usage		%
Average Use per Program		Hours per day
Average Volume Control (VC) Setting	Soft Moderate Loud	dB deviation from prescribed setting
Overall VC usage	Soft Moderate Loud	% of time VC up/down
Relative Microphone Mode Usage	Surround Split Dir Full Dir	%
Relative Listening Environment Usage	Quiet Speech Only Speech in Noise Noise Only	%

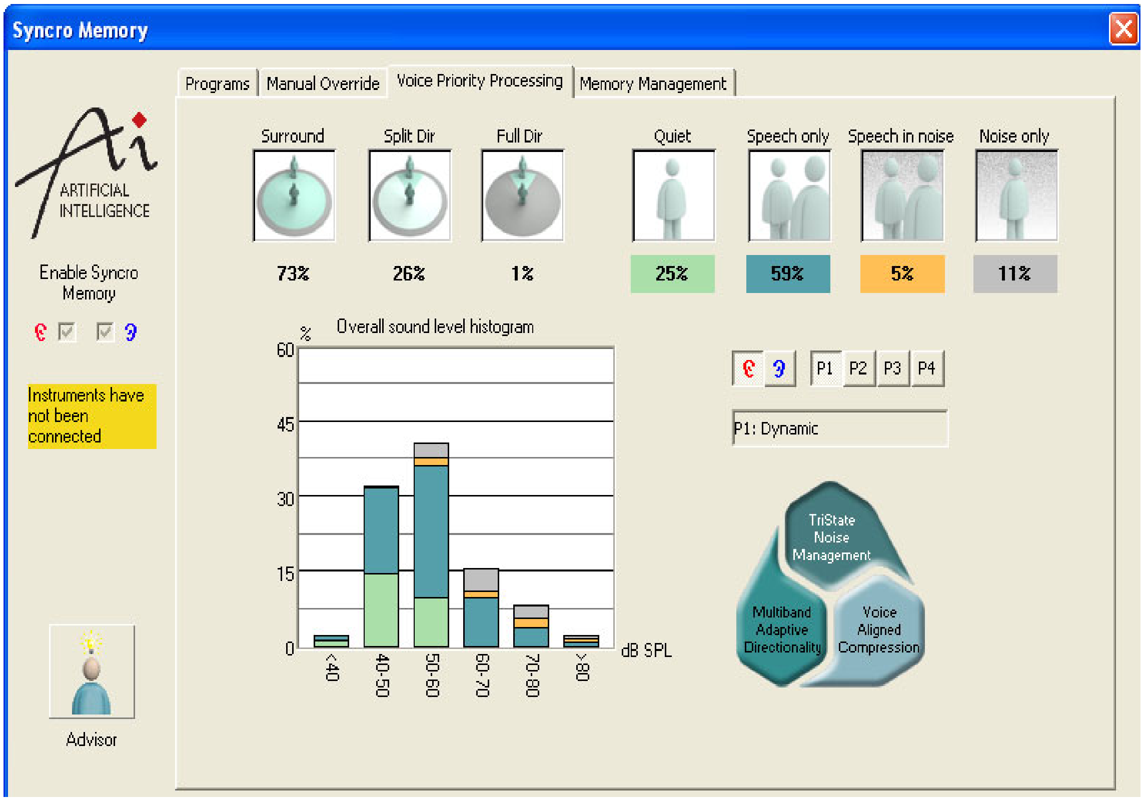

Figure 4. Oticon Syncro Memory display screen example showing the "envirogram"

Table 3. Data logging information accessible for GN ReSound Metrix

Data Logged	Situations	Units
Total Usage		Hours
Average Total Usage		Hours per day
Usage Time per Program	Each Program	Hours
Total Number of Instrument Uses		Frequency
Hours per Use	0-4 hours 4-8 hours 8-12 hours 12-16 hours 16-20 hours 20+ hours	Frequency
Number of Program Changes		Frequency
Average Sound Level	Each Program	dB SPL
Listening Environment Usage	Quiet Speech (soft) Speech (Loud) Speech in Noise (Moderate) Speech in Noise (Loud) Noise (Moderate) Noise (Loud)	Hours
Softswitch Usage	Each Program	Hours
Mean and SD Volume Control (VC) Change	Each Program Quiet Speech (soft) Speech (Loud) Speech in Noise (Moderate) Speech in Noise (Loud) Noise (Moderate) Noise (Loud)	dB
Mean and SD VC change over time	5 hours 15 hours 30 hours 60 hours 120 hours 240 hours 320 hours	dB
Number of VC adjustments (Increase and Decrease)	Quiet Speech (soft) Speech (Loud) Speech in Noise (Moderate) Speech in Noise (Loud) Noise (Moderate) Noise (Loud)	dB

2.3 Procedure

All participants were given routine clinical instructions on hearing aid use at the fitting appointment. No task was required of the participants except to carry out their normal daily activities between the fitting and follow-up appointments. This was ensured as the participants were unaware of their involvement in the study until data were collected. The data logging information was obtained as part of a routine follow-up appointment which was held up to nine weeks after the initial hearing aid fitting. The data were automatically downloaded onto the audiologist's computer when the hearing aids were connected for fine-tuning, via the manufacturer's fitting software.

2.4 Measurement and Data Analysis

The total time usage and the time usage information for different listening programs, listening environments, microphone modes and sound levels were manually recorded by the researchers from the computer display of the logged data. Since each participant spent all or the majority of their time in listening program 1 (Right ear: Mean = 88.9%, SD = 15.8%, n = 57; Left ear: Mean = 90%, SD = 14.5%, n = 57), which is a general listening program, the information for this program was chosen for analysis.

2.4.1 Recorded Data Logging Information

For the Syncro hearing aids, the recorded data logging information included average total usage per day in hours, relative program usage in percent, the relative microphone mode usage, which included "Surround", "Split", and "Full", and the relative listening environment usage, which included "Quiet", "Speech Only", "Speech in Noise", and "Noise Only". The envirograms showing overall sound levels were also recorded.

For the Metrix hearing aids, the recorded data logging information included average total use per day in hours, total usage time per program in hours, and the total listening environment usage in hours, which included "Quiet", "Speech (soft)", "Speech (loud)", "Speech in Noise (moderate)", "Speech in Noise (loud)", "Noise (moderate)", and "Noise (loud)".

2.4.2 Data Reduction

The Oticon software displays listening environment information in four levels, whereas the GN ReSound software displays the same information in seven levels. To be reduced to the same four levels as the Oticon data for better comparison, the GN ReSound data were reorganized, with the "Speech (soft)" and "Speech (loud)" levels grouped as "Speech Only", "Speech in Noise (moderate)" and "Speech in Noise (loud)" as "Speech in Noise", and "Noise (moderate)" and "Noise (loud)" as "Noise Only".

2.5 Statistical Analysis

All measures of time usage not presented as a percentage were transformed into a percentage by dividing the time measured for a specific category by the total time recorded and then multiplying the ratio by 100. To make full use of the data available, data were organized in different ways for discriminate analysis. There are three main independent variables in this study. The first independent variable is listening situation with four levels, namely, "Quiet", "Speech Only", "Speech in Noise", and "Noise Only". The second independent variable is microphone mode with three levels, namely, "Surround", "Split", and "Full". The third independent variable is sound level, with six levels in dB SPL, namely, smaller than 40 dB ("<40"), between 40 and 50 dB ("40-50"), between 50 and 60 dB ("50-60"), between 60 and 70 dB ("60-70") and greater than 80 dB (">80"). To determine the general pattern of the hearing aid user's time spent in different listening environments, the data were analysed with descriptive statistics as well as a series of One-Way or Two-Way Analysis of Variances (ANOVAs). Nonparametric equivalents of these tests were used if the data were found to have failed the test of normality or equal variance. The significance level was set at 0.05. Upon finding of a significant effect, a series of post-hoc multiple pair-wise comparison procedures using the Dunn's or Tukey test were performed. SigmaStat software was used for all statistical analyses.

3 Results

This chapter provides results from a series of analyses conducted on the whole set of the recorded data logging data obtained from the 57 participants as well as for subsets of the data.

3.1 Hours of Use

The mean average hours of use per day for the 57 participants was 7.6 hours for the right ear data (SD = 3.8) and 7.3 hours for the left ear data (SD = 3.7). A Wilcoxon Signed Rank Test revealed no significant difference between the right and left ear data ($W = -245$, $T+ = 350.5$, $T- = 595.5$, $p = 0.1$).

3.2 Listening Environment Classifications

This section presents results concerning the variation of the measure of time spent in each listening environment, along with results from further analyses examining effects of age and instrument style on the measure of time spent.

3.2.1 Environment Effect

Results of a two-way repeated-measures ANOVA conducted on data from the 57 participants revealed a significant environment effect [$F(3, 168) = 77.3$, $p < 0.001$], but no significant ear effect [$F(1, 56) = 0.006$, $p = 0.9$] and no significant interaction between ear and listening environment [$F(3, 168) = 0.2$, $p = 0.9$] on the measure of time spent. Since measures of time spent in different listening environments were not found to differ between ears, data from the right and left ears were averaged to simplify data analysis. The resulting mean percentage of time spent in each listening environment for all participants is shown in Figure 5.

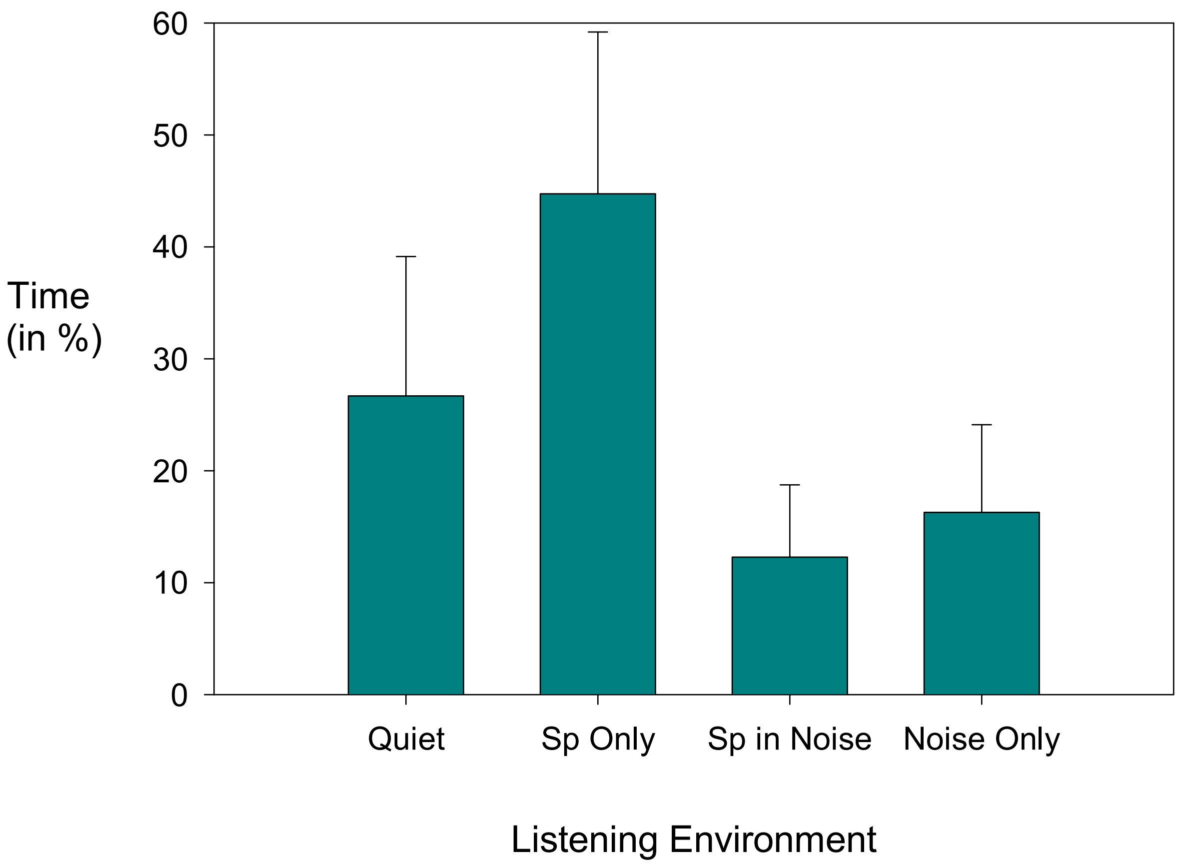

Figure 5. Mean percentage of the time spent in four listening environments, including "Quiet", "Speech (sp) Only", "Sp in Noise", and "Noise Only".

As shown in Figure 5, the majority of the hearing aid users' time was spent, on average, in "Speech Only" situations (44.8%). This was followed by "Quiet" (26.7%), "Noise Only" (16.3%) and "Speech in Noise" (12.3%) situations. Results of a Kruskal-Wallis one-way ANOVA on ranks conducted on the data averaged for both ears from the 57 participants showed a significant difference among measures of time spent in different listening situations ($H = 129.3$, $df = 3$, $p < 0.001$). Post-hoc multiple pair-wise comparisons using the Dunn's test showed a significant difference among measures of time spent for all pair-wise comparisons between different listening environments except for the comparison between "Speech in Noise" and "Noise Only" situations.

To examine the distribution of time spent in listening environments where noise is present, the data for time spent in "Speech in Noise" and "Noise Only" situations were summed for each of the 57 participants. The average time spent in listening environments with noise present was 28.6% ($SD = 12.5$). The data passed a Kolmogorov-Smirnov test of normality (K-S Dist. = 0.1, $p = 0.1$), i.e., the data matches the pattern expected if the data was drawn from a population with a normal distribution.

3.2.2 Age by Listening Environment Interaction

To determine whether age interacted with listening environment in affecting the measure of time spent, the 57 participants were divided into age groups of ten years, including 50-59 years ($n = 9$), 60-69 years ($n = 17$), 70-79 years ($n = 18$), and 80-89 years ($n = 9$). The four participants under 50 years of age were excluded from this analysis due to the small sample size. Results of a two-way repeated-measures ANOVA conducted on the data averaged for both ears from the 53 participants revealed a significant environment effect [$F(3,49) = 75.4$, $p < 0.001$], but no significant age effect

[F(3,49) = 0.7, p= 0.5] and no significant effect of interaction between age and listening environment [F(9,47) = 0.8, p = 0.6] on the measure of time spent.

3.2.3 Style by Listening Environment Interaction

To determine whether instrument style interacted with listening environment in affecting the measure of time spent, participants were regrouped by the style of the hearing aid. The one participant who used a CIC style hearing aid was excluded from the analysis due to the small sample size. The participant who wore both a BTE and an ITE was also excluded. Results of a two-way repeated-measures ANOVA conducted on the data averaged for both ears from the 55 participants with hearing aids in one of the three styles (i.e., ITC, ITE, and BTE) revealed a significant environment effect [F(3,52) = 86, p< 0.001], no significant style effect [F(2,52) = 0.2, p = 0.8], and a significant interaction between style and listening environment [F(6,156) = 4.4, p<0.001] on the measure of time spent. Three one-way ANOVAs were performed separately on the data for each of the three styles. Results of one-way ANOVAs conducted on the data averaged for both ears from the 26 BTE and 14 ITE hearing aid users respectively showed a significant difference among measures of time spent in different listening environments for data from BTE [F(3,100) = 31.4, p < 0.001] and data from ITE [F(3,52) = 41.0, p<0.001] styles. A Kruskal-Wallis one-way ANOVA on ranks performed on data averaged for both ears from the 15 ITC hearing aid users also showed a significant difference among measures of time spent in different listening environments (H=37.5, df = 3, p<0.001). The results of post-hoc multiple pair-wise comparisons using the Tukey test and the Dunn's test are shown in Figure 6. As shown in Figure 6, no significant difference was found among measures of time spent in different listening environments for the pair-wise comparison between "Speech in Noise" and "Noise Only" situations for any of the three hearing aid styles. In addition, for the ITC and ITE styles, a significant difference among measures of time spent in different listening environments was found for all pair-wise comparisons involving the "Speech Only" situation.

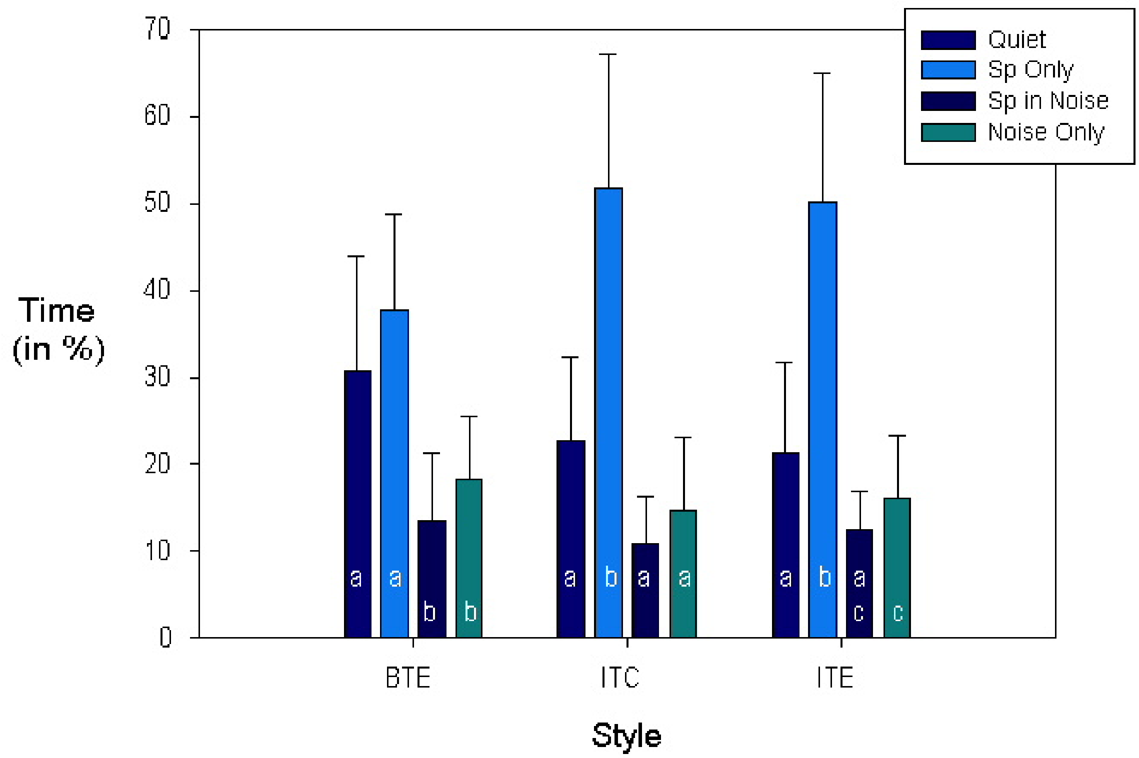

Figure 6. Mean percentage of the time spent in four listening environments, including "Quiet", "Speech (sp) Only", "Sp in Noise", and "Noise Only" for three hearing aid styles, including BTE, ITC, and ITE. Group means that are significantly different from each other are labelled with different letters.

3.2.4 Gender Interaction

As mentioned previously, the fifty-seven participants in this study included 50 males and 7 females. For the concern that gender may interact with listening environment in affecting the measure of time spent, the female listening environment data were further isolated from the sample for separate analysis. A one-way ANOVA conducted on the data averaged for both ears from the 7 female participants showed a significant difference among measures of time spent in different listening environments [$F(3,24)$ = 22.8, p<0.001]. A Kruskal-Wallis one-way ANOVA on ranks conducted on the data averaged for both ears from the 50 male participants showed a significant difference among measures of time spent in different listening environments ($H = 114.8$, $df = 3$, $p < 0.001$). Results of post-hoc multiple pair-wise comparisons using the Tukey or Dunn's test conducted separately on the male and female data are shown in Figure 7. As shown in Figure 7, comparisons between listening environments from separate analyses of female and male data yielded similar results, with no significant difference found among measures of time spent in different listening environments for the pair-wise comparison between "Speech in Noise" and "Noise Only" situations for either the female or the male data.

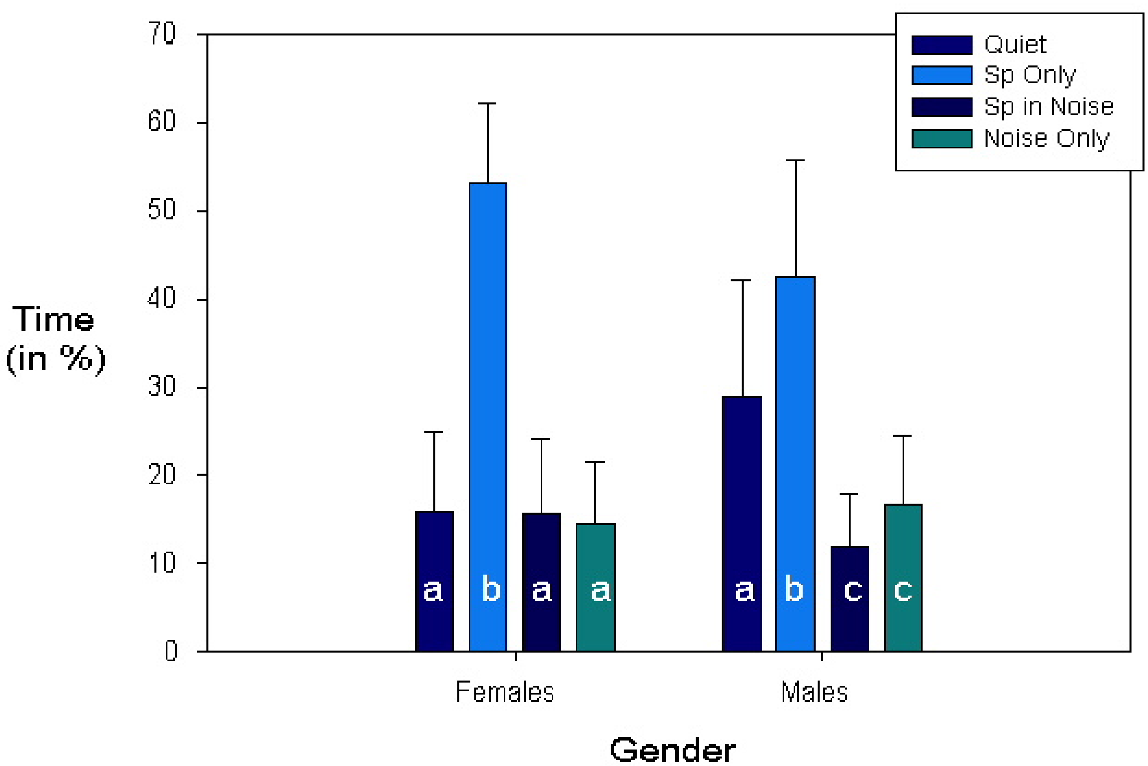

Figure 7. Mean percentage of the time spent in four listening environments, including "Quiet", "Speech (sp) Only", "Sp in Noise", and "Noise Only" for female and male participants. Group means that are significantly different from each other are labelled with different letters.

3.2.5 Session-to-session Reliability

Sixteen of the participants had more than one follow-up session during which data logging information was obtained from different periods of time. The data from these extra follow-up sessions were also manually recorded by the researchers to assess session-to-session measurement reliability. A two-way repeated measures ANOVA performed on data from participants ($n = 16$) who had data available for two sessions revealed a significant environment effect [$F(3,45) = 36.9$, $p<0.001$] but no significant session effect [$F(1,15) = 1.8$, $p = 0.196$] and no significant interaction between session and listening environment [$F(3,45) = 0.3$, $p = 0.8$] on time spent. Subsequent Friedman repeated-measures ANOVAs revealed a significant difference among the measures of time spent in different listening environments for the first session ($\chi 2= 35.8$, $df = 3$, $p <0.001$) and for the second session ($\chi 2= 31.1$, $df = 3$, $p< 0.001$). Post-hoc multiple pair-wise comparisons using the Tukey test for both sessions showed a significant time usage difference among all pair-wise comparisons between different listening environments except for the comparisons between "Quiet" and "Speech Only", "Quiet" and "Noise Only", and "Speech in Noise" and "Noise Only".

3.2.6 Instrument Variability

To determine whether the instrument manufacturer interacted with listening environment in affecting the measure of time spent, two one-way ANOVAs on ranks were performed separately on data from participants with Metrix hearing aids ($n = 29$) and on data from those with Syncro hearing aids ($n = 28$). For the Metrix hearing aids, results of the one-way ANOVA revealed a significant difference among the measures of time spent in different listening situations [$F(3,112) = 32.6$, $p < 0.001$]. For the Syncro hearing aids, a significant difference was also found among the time spent in different listening situations using the Kruskal-Wallis one-way ANOVA on ranks ($H = 72.5$, $df = 3$, $p < 0.001$). Results of post-hoc multiple pair-wise comparisons using the Tukey or Dunn's test conducted separately on the Syncro and Metrix data are shown in Figure 8. As shown in Figure 8, no significant difference was found among measures of time spent for the pair-wise comparison between "Speech in Noise" and "Noise Only" situations for both the Metrix and Syncro hearing aids.

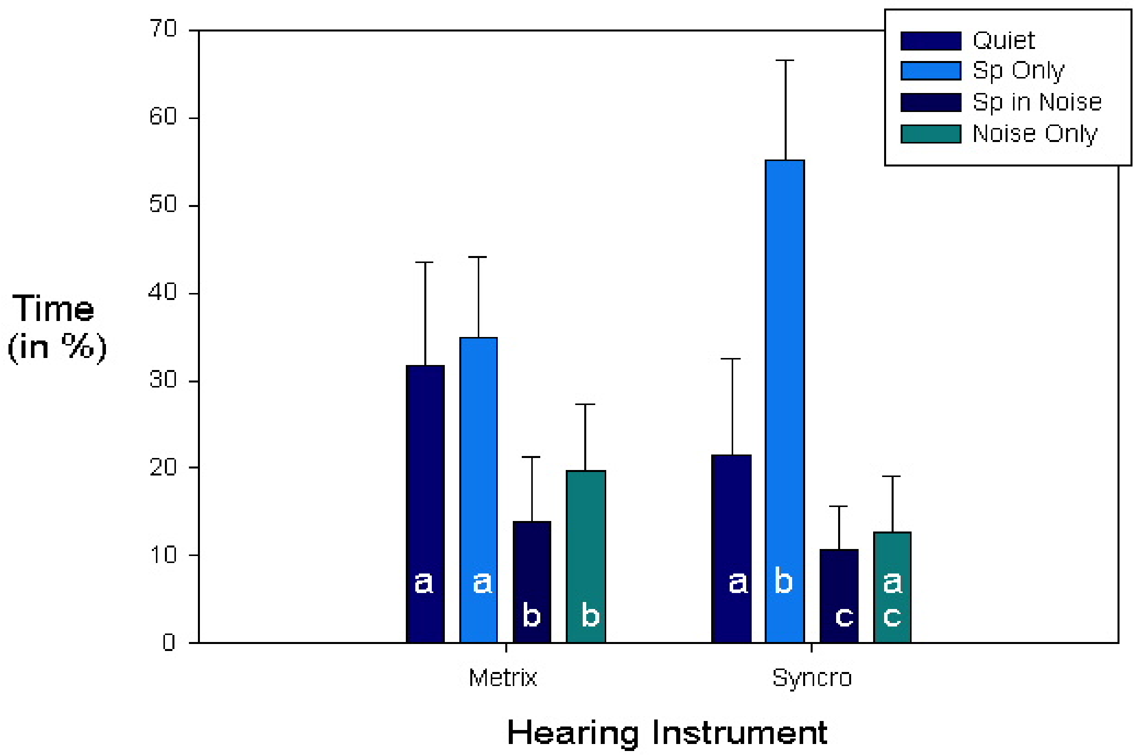

Figure 8. Mean percentage of the time spent in four listening environments, including "Quiet", "Speech (sp) Only", "Sp in Noise", and "Noise Only" for Metrix and Syncro hearing aids. Group means that are significantly different from each other are labelled with different letters.

3.3 Microphone Mode

This section details results from analyses concerning the variation of the measure of time spent in each microphone mode. As the Oticon Syncro hearing aid provides data logging information for the automatic use of its three microphone modes (i.e., surround, split-directional, and full directional), data from the 28 participants with Syncro hearing aids were included, except for one participant who wore a CIC style of hearing aid, which is not equipped with a directional microphone. Results from further analyses examining effects of interaction between microphone and both age and instrument style on the measure of time spent are also reported.

3.3.1 Microphone Mode Effect

Results of a two-way repeated-measures ANOVA conducted on data from the 27 participants with Syncro hearing aids equipped with directional microphones revealed a significant microphone mode effect [$F(2,52) = 201.8$, $p < 0.001$] but no significant ear effect [$F(1,26) = 1.0$, $p = 0.3$] and no significant interaction between ear and microphone mode [$F(2,52) = 0.2$, $p = 0.8$] on the measure of time spent. Since measures of time spent in different microphone modes were not found to differ between ears, data from the left and right hearing aids were averaged to simplify data analysis. The resulting mean percentage of time spent in each microphone mode for the 27 participants is shown in Figure 9.

As shown in Figure 9, the majority of the hearing aid users' time was spent, on average, in "Surround" microphone mode (74.3%), followed in order by "Split" directional mode (22.3%) and "Full" directional mode (3.5%). Results of a Kruskal-

Wallis one-way ANOVA on ranks conducted on the data averaged for both ears from the 27 participants revealed a significant difference among the time spent in different listening microphone modes ($H = 68.4$, $df = 2$, $p < 0.001$). Post-hoc multiple pair-wise comparisons using the Dunn's test showed a significant difference for all pair-wise comparisons between different microphone modes

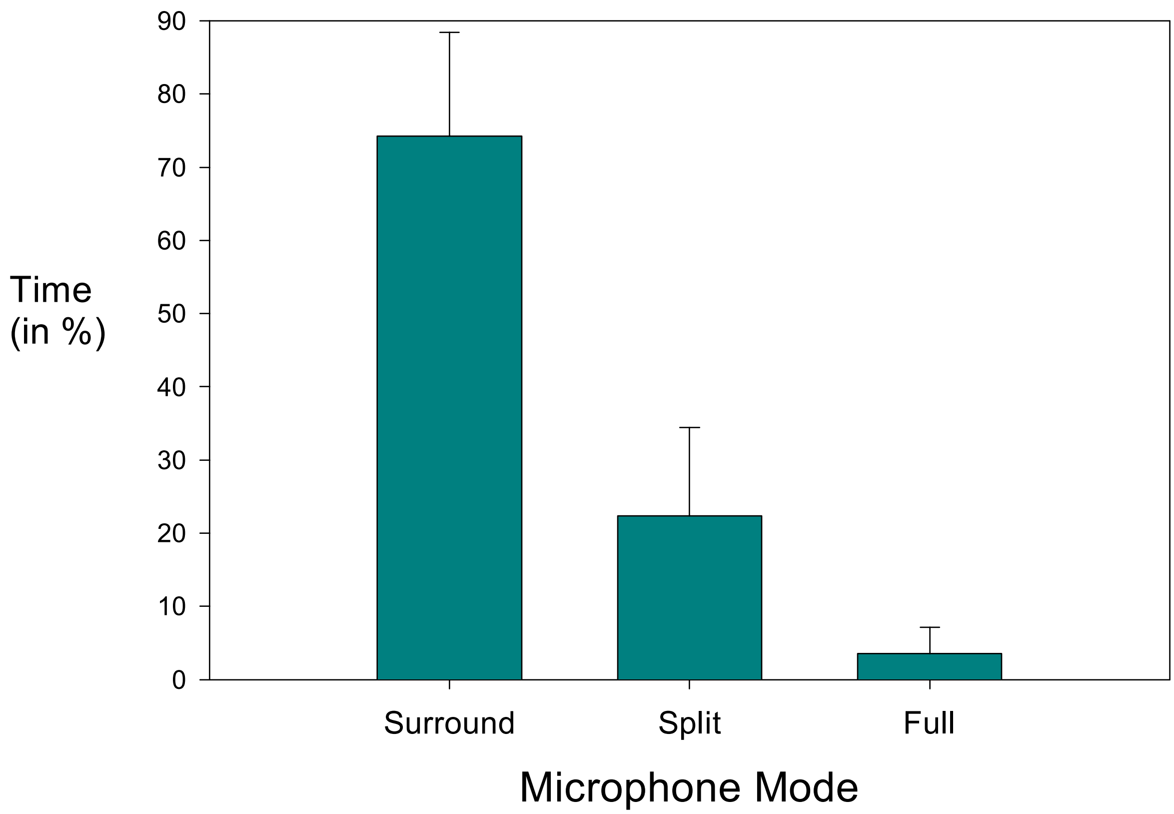

Figure 9. Mean percentage of the time spent in three microphone modes, including "Surround", "Split" directional, and "Full" directional.

3.3.2 Age by Microphone Interaction

To determine whether age interacted with microphone mode in affecting the measure of time spent, the 27 participants with Syncro hearing aids equipped with directional microphones were divided into age groups of ten years, including 50-59 years (n = 5), 60-69 years (n = 7), 70-79 years (n = 8), and 80-89 years (n = 4). The three participants under 50 years of age were excluded from this analysis due to the small sample size. Results of a two-way repeated measures ANOVA conducted on the data averaged for both ears from 24 participants revealed a significant microphone mode effect [$F(2,40) = 365.4$, $p<0.001$] but no significant age effect [$F(3,20) = 0.6$, $p= 0.6$] and no significant interaction between microphone mode and age [$F(6,40) = 1.4$, $p = 0.2$] on the measure of time spent.

3.3.3 Style by Microphone Interaction

To determine whether instrument style interacted with microphone mode in affecting the measure of time spent, the 27 participants with Syncro hearing aids equipped with directional microphones were regrouped by the style of their hearing aid. There were 2 participants with BTE style hearing aids, 11 ITE, 13 participants with ITC hearing aids, and 1 participant with both a BTE and an ITE. The two participants with BTE hearing aids and the 1 participant with both BTE and ITE were excluded from further analysis due to the small sample size. Results of a two-way repeated-measures ANOVA conducted on the data averaged for both ears from 24 participants revealed a significant microphone mode effect [$F(2,22) = 164.1$, $p < 0.001$] but no significant style effect [$F(1,22) = 1.2$, $p = 0.3$] and no significant interaction between microphone mode and style [$F(2,44) = 0.4$, $p = 0.7$] on the measure of time spent.

3.4 Sound Levels

As 28 participants with Syncro hearing aids had the sound level "envirogram" available in their data logging feature, data from these participants were submitted to further analysis to determine the variation in the measure of time spent in each overall sound level. Results from further analyses examining effects of interaction between overall sound level and both age and instrument style on the measure of time spent are also reported.

3.4.1 Sound Level Effect

A two-way repeated-measures ANOVA conducted on data from the 28 participants revealed a significant sound level effect [$F(5,135) = 17.7$, $p < 0.001$] but no significant ear effect [$F(1,27) = 0.4$, $p = 0.5$] and no significant interaction between sound level and ear [$F(5,135) = 0.01$, $p = 1.0$] on the measure of time spent. Since measures of time spent in different overall sound levels were not found to differ between ears, data from the right and left ears were averaged to simplify data analysis. The resulting mean percentage of time spent in each sound level for the 28 participants is shown in Figure 10.

As shown in Figure 10, the majority of hearing aid user time was spent in an overall sound level less than 70 dB SPL (84.9%). Results of a Kruskal-Wallis one-way ANOVA on ranks conducted on the data averaged for both ears from the 28 participants revealed a significant difference among measures of time spent in different overall sound levels ($H = 80.2$, $df = 5$, $p < 0.001$). Results of post-hoc multiple pair-wise comparisons using the Dunn's test are also displayed in Figure 10, which shows that no significant difference was found among measures of time spent in different overall sound levels for the pair-wise comparisons between all sound levels from "<40" to "60-70" dB SPL.

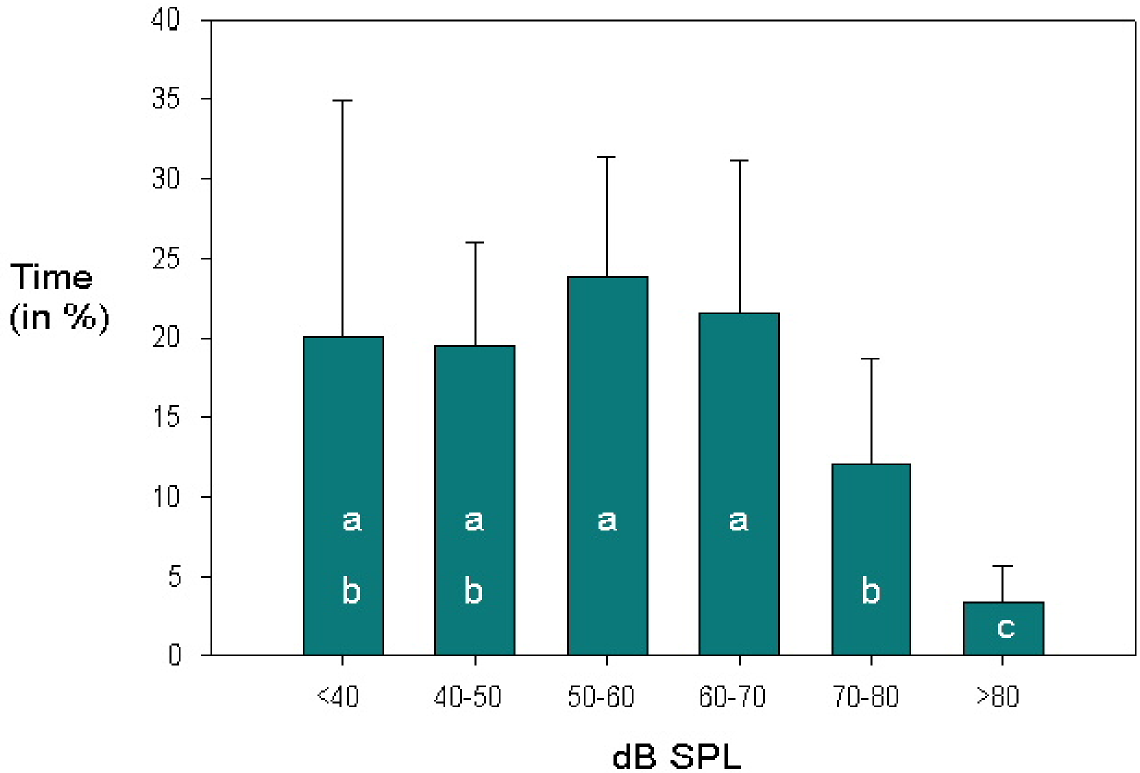

Figure 10. Mean percentage of the time spent in six overall sound levels. Group means that are significantly different from each other are labelled with different letters.

3.4.2 Age by Sound Level Interaction

To determine whether age interacted with sound level in affecting the measure of time spent, the 28 participants with Syncro hearing aids were divided into age groups of ten years, including 50-59 years (n = 5), 60-69 years (n = 8), 70-79 years (n = 8), and 80-89 years (n = 4). The three participants under 50 years of age were excluded from this analysis due to the small sample size. A two-way repeated-measures ANOVA conducted on the data averaged for both ears from 25 participants revealed a significant sound level effect [$F(5,21) = 19.8$, $p < 0.001$] but no significant age effect [$F(3,21) = 0.5$, $p = 0.7$] and a significant interaction between age and sound level [$F(15,105) = 1.8$, $p = 0.04$] on the measure of time spent. Four one-way ANOVAs were performed separately on data for each of the four age groups. Results of a series of Kruskal-Wallis one-way ANOVAs on ranks showed a significant difference among measures of time spent in different overall sound levels for the 50-59 years age group (H = 36.2, df = 5, $p < 0.001$), the 60-69 years age group (H = 26.0, df = 5, $p < 0.001$), and the 80-89 years age group (H = 17.5, df = 5, $p < 0.001$). A one-way ANOVA on ranks showed a significant difference among measures of time spent in different overall sound levels for the 70-79 years age group [$F(5,42) = 4.8$, $p < 0.001$]. The results of post-hoc multiple pair-wise comparisons using the Tukey and Dunn's test are shown in Figure 11. As shown in Figure 11, the pair-wise comparisons among measures of time spent in different overall sound levels yielded identical results for the 60-69 and 70-79 years age groups.

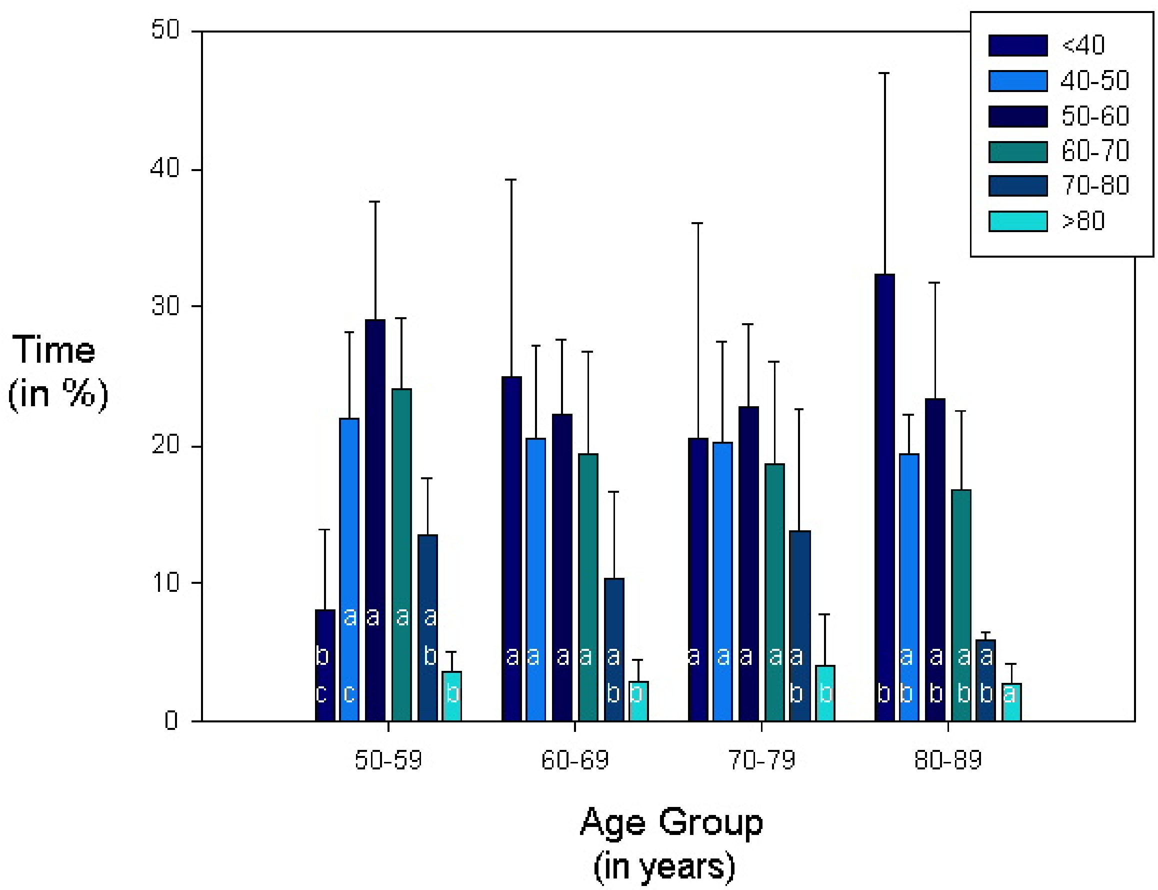

Figure 11. Mean percentage of the time spent in six overall sound levels for four different age groups, including 50-59 years, 60-69 years, 70-79 years, and 80-89 years. Group means that are significantly different from each other are labelled with different letters.

3.4.3 Style by Sound Level Interaction

To determine whether instrument style interacted with sound level in affecting the measure of time spent, the 28 participants with Syncro hearing aids were sorted according to the style of their hearing aid, which resulted in 1 participant with both a BTE and an ITE, 1 participant with a CIC, 2 participants with BTE, 11 participants with ITE, and 13 participants with ITC hearing aids. Four participants, including one with a CIC, one with a BTE and a ITE, and two with BTE hearing aids, were excluded from this analysis due to the small sample size. A two-way repeated measures ANOVA conducted on the data averaged for both ears from 24 participants revealed a significant sound level effect [$F(5,22) = 15.4$, $p < 0.001$] but no significant style effect [$F(1,22) = 0.006$, $p = 0.9$] and no significant interaction between sound level and style [$F(5,110) = 0.6$, $p = 0.7$] on the measure of time spent.

3.5 Listening Environments and Overall Sound Levels

For the twenty participants whose hearing aids contained the 'envirogram' feature which specified the time spent in each of the listening environments, including 'Quiet', 'Speech Only', 'Speech in Noise', and 'Noise Only', at each sound level, the mean percentages of time spent in each listening environment within each sound level category are shown in Figure 12. The standard deviations are shown in Table 4. As shown in Figure 12, the three listening environments of 'Speech Only', 'Speech in Noise', and 'Noise Only' are present in all six overall sound levels. The 'Speech Only' situation accounts for a large proportion of each of the six overall sound levels. As shown in Table 4, the standard deviations are large relative to the mean time spent in different listening environments, in five cases being larger than the mean.

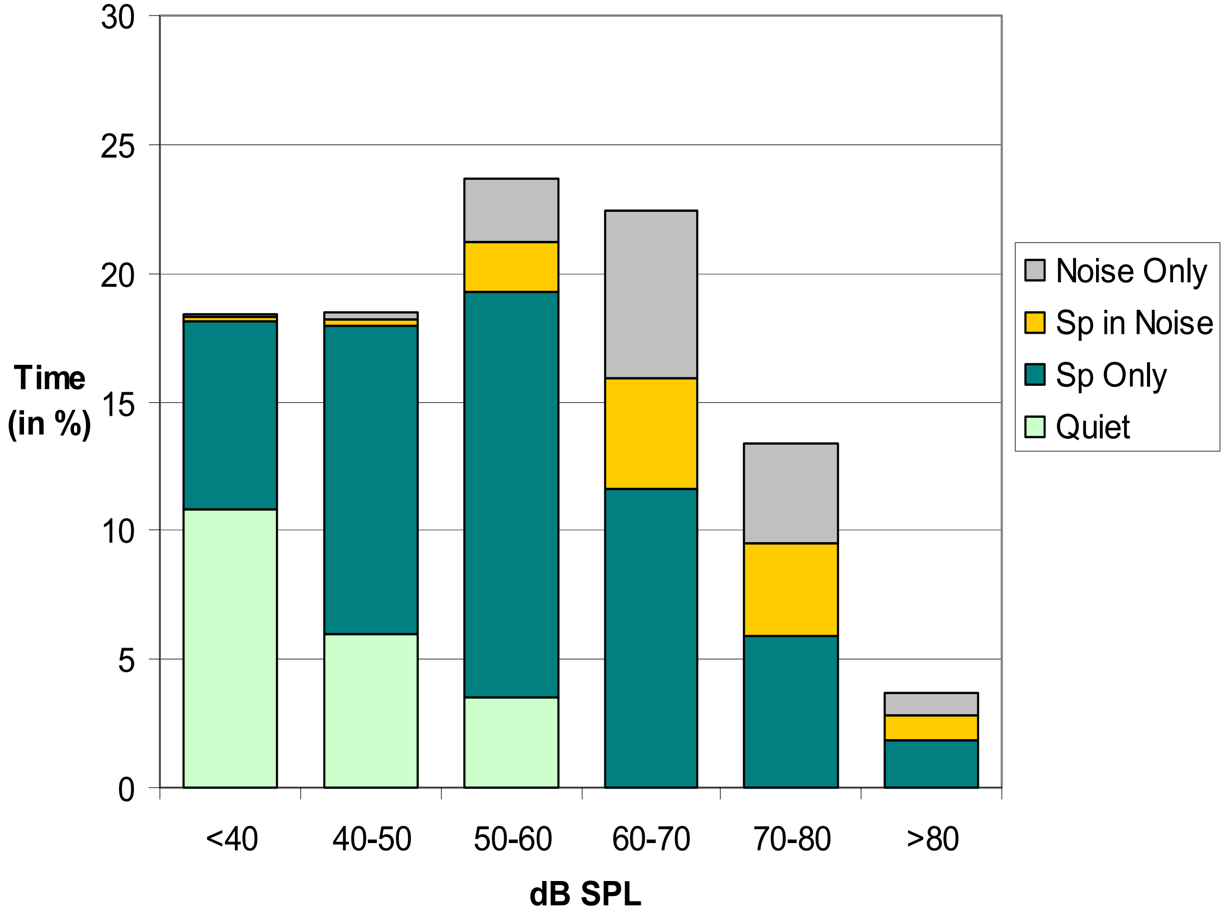

Figure 12. Mean percentage of time spent in four different listening environments, including 'Quiet', 'Speech (sp) Only', 'Sp in Noise', and 'Noise Only' within six overall sound levels.

Table 4. Mean and standard deviations for time spent in four different listening environments within six overall sound levels.

	Quiet		Speech Only		Speech in Noise		Noise Only	
dB SPL	mean	sd	mean	sd	mean	sd	mean	sd
<40	10.8	8.7	7.4	8.6	0.1	0.3	0.2	0.5
40-50	5.9	2.9	12	4.3	0.2	0.4	0.3	0.5
50-60	3.6	1.3	15.7	5.5	2	1.7	2.4	2.1
60-70	0	0	11.7	4.2	1.3	3.5	6.5	5.3
70-80	0	0	5.9	3.6	3.6	2.2	3.9	2.3
>80	0	0	1.9	1.4	1	0.8	0.9	0.7

3.6 Summary of Results

The majority of the participants' time was spent, on average, in "Speech Only" situations. A significant difference was found among the measures of time spent in all four different listening environments, except for between the measures of time spent in "Speech in Noise" and "Noise Only" situations. No significant interaction was found between the measure of time spent in different listening environments and the age or style of hearing aid of the participants. The majority of the participants' time was spent, on average, in "Surround" microphone mode. A significant difference was found among the measures of time spent in all three microphone modes. No significant interaction was found between the measure of time spent in different microphone modes and the age or style of hearing aid of the participants. The majority of the participants' time was spent, on average, in overall sound levels less than 70 dB SPL. A significant interaction was found between the measure of time spent in different overall sound levels and the age of the participants, but no significant interaction was found between the measure of time spent in different overall sound levels and the style of hearing aid of the participants. The three listening environments of "Speech Only", "Speech in Noise" and "Noise Only" were present in all six of the overall sound levels examined.

4 Discussion

This chapter will discuss the main findings regarding the general pattern of adult hearing aid users' time spent in different listening environments, microphone modes and sound levels and the effect of age and instrument style on the measure of time spent, compare the present findings with those in the literature, describe the limitations of the study, outline clinical implications, and suggest future research on the topic.

4.1 Listening Environments

The overall pattern of the hearing aid users' behaviours, in terms of time spent in different listening environments, showed that the listening environments most often experienced by the hearing aid user were "Speech Only" situations, followed by "Quiet" situations and then by two situations with similar amounts of time usage, "Speech in Noise" and "Noise Only". As the age range covered in this study is typical of that of private hearing aid clients in New Zealand, this finding can be useful to clinicians in estimating the common needs of clients within this age group.

The present finding that time spent in different listening environments, as observed through the hearing aid feature of data logging, was most dominant in the

"Speech Only" situation supports the findings in subjective studies. In a study with a smaller sample size (18 participants), Jensen and Nielsen (2005) examined time spent in seven listening categories, including "conversation with several persons", "conversation with one person", "other people's speech or conversation", "TV/Radio–informative programs", "everyday sounds", "music", and "others". Although the categories in Jensen and Nielsen's (2005) study were not classified as being 'in quiet' or 'in noise', the categories that included speech of some sort reportedly made up approximately 60% of the recordings made by the participants, which is close to the 57.1% of time found in this study for the listening environments "Speech Only" and "Speech in Noise" combined. Therefore, the automatic recordings of the data logging feature in this study appear to yield results compatible with findings from the hearing aid users' self-chosen recordings in Jensen and Nielsen (2005), both revealing a relatively large amount of time spent in situations where speech is present.

The measure of time spent in environments where noise was present in this study were compared with that in the study by Walden et al. (2004). In this study, the average time spent in environments with noise present was 28.6%, combining the "Speech in Noise" and "Noise Only" situations. Walden et al. (2004), in studying hearing aid microphone preference, found that their 17 participants were in active listening situations in environments where noise was present 61.8% of the time. This discrepancy on the time spent in noisy environment may be related to various methodological differences between the two studies. Firstly, although one might have expected the automatic and objective recordings of the data logger in this study to report more time spent in situations with noise present than the Walden et al. (2004) study, where only active listening situations, i.e., where the participants were actively listening to speech or non-speech sounds such as music or nature, were recorded, it is also likely that even more time spent in listening environments without noise present would be recorded by the data logger. For example, with many non-active listening situations being recorded by the data logger, one might expect situations with no background noise, i.e., “Quiet” situations, to have a relatively higher percentage of time spent, which is exactly what the present study has found. Another example showing data logging would yield more time spent in non-noisy environments is a situation where a participant is not actively listening while reading the paper if the television was on broadcasting speech without noise or a spouse was talking on the phone in the same room. While data logging would identify this situation as “Speech Only”, it is most likely that participants in Walden et al. (2004)’s study would not have included it in their log of active listening situations. A second methodological difference between Walden et al. (2004) and the present study that might be related to the different findings regarding the time spent in noisy environments was the definition of noise. Since there was no indication in Walden et al.’s (2004) study that participants were given any definition of background noise, the criterion used by their participants in identifying noisy environments may not be compatible with that set for the hearing aids employed in the present study. The third methodological difference that might be related to the discrepancy in time spent in noisy environments was the years of experience of hearing aid use. The fact that participants in the present study was much less experienced in hearing aid use than the seventeen participants in Walden et al’s (2004) study (mean years of experience = 13.6 years, SD = 9.1, range = 2-33) may have contributed to the difference between the two studies on the measure of time spent in environments with noise present. Further studies are needed to determine whether less experienced hearing aid users, like those in the present study, would tend to spend less time in noisy environments.

Another aspect of the overall pattern of hearing aid user behaviour in terms of time spent in different listening environments is the difference in time spent between “Speech Only” and “Speech in Noise” situations. This difference may be important clinical information as understanding speech in noise can be the most difficult situation for a hearing impaired person. As neither Jensen and Nielsen’s (2005) nor Walden et al.’s (2004) studies made the distinction between these two “speech” situations, the objective measurements made with the data logging feature in this study are informative in this respect. However, the data logging feature does not provide information about the importance of each listening situation to the hearing aid user. For example, Jensen and Nielsen (2005) suggested that listening where a response is required by the hearing aid user is far more important to the hearing aid user than passive listening, a fact that cannot be determined based on data logging information. Therefore, although the majority of the hearing aid user’s time may be spent in “Speech Only” situations, it may be the small amount of time spent in a “Speech in Noise” situation which is subjectively most important for the hearing aid user.

In terms of clinical implications, the general pattern of time spent in different listening environments is useful to the clinician as it can identify the need for various hearing aid features. Using the data from the present study as the norm, deviations from the pattern found in this study can be identified. For example, the summed data for the “Speech in Noise” and “Noise Only” situations were shown to have a normal distribution, with a mean of 28.6% (SD = 12.5). Using a z-score of 1.65, the data suggests that if a client has a measure of time spent in “Speech in Noise” and “Noise Only” situations combined greater than approximately 49%, then they are in more noise than 95% of users and would therefore potentially get the most benefit from noise reduction algorithms and directional microphones. Conversely, if these values total less than approximately 8% then they potentially do not have as great a need to use such features at present.

In summary, findings from this study regarding time spent in different listening environments as compared with previous findings indicate that the average listening environment time usage data may be useful to the clinician. However it is noteworthy that the objective data logging cannot give information on the relative importance of the different listening environments.

4.2 Microphone Mode

In terms of time spent in different microphone modes, the present finding is that the microphone mode most often experienced by the hearing aid user was 'Surround' mode, followed in order by "Split" and "Full" directional modes. This is consistent with the results for the listening environment data, where the majority of time was spent in "Speech Only" and "Quiet" situations, as these are situations which would not instigate a change to a directional microphone mode. In fact, the average percentage of time spent in situations where no noise was present was 71.6%, compared to 74.3% of time spent in "Surround" mode. This overall pattern of hearing aid user behaviour in terms of time spent in different microphone modes will be discussed in relation to previous findings in the literature as follows.

Walden et al. (2004) found that the directional mode of the hearing aid was preferred in the presence of background noise and with the primary signal source located in "front" of and "near" to the listener. They found that these situations make up 39.5% of total active listening situations and 34.5% of total active listening time. In comparison, relative time spent in "Split" or "Full" directional modes in this study was, on average, 25.8%. Considering that the Walden et al. (2004) study recorded only active listening situations, it is not surprising that the percentage from this study, which measured all listening situations, to have a relatively higher percentage of time spent in surround mode situations (i.e. potentially non-active listening situations). Therefore, the objective recordings of microphone mode usage by the data logging feature in this study appeared to yield results compatible with those from the Walden et al. (2004) study.

In terms of clinical implications, it is noteworthy that there was no significant difference between ears for the time spent in each microphone mode. This suggests that an audiologist can be confident that both hearing aids are switching to an appropriate microphone mode at the same time. Also, it may suggest that hearing aids not equipped with technology that allows communication between ears, such as that available in the Siemens Acuris hearing instrument (Powers & Burton, 2005) may not be at a disadvantage, as the hearing aids in this study appear to switch to the same mode on both sides despite not having that technology.

In summary, the average microphone mode time usage data may be useful to the clinician, as it demonstrates that they may not be placing clients at a disadvantage by choosing a hearing aid without the ability to communicate between ears.

4.3 Sound Level

In terms of time spent in different overall sound levels, the main findings of this study were that similar amounts of time were spent in the four ranges under 70 dB SPL (i.e., “<40 dB”, “40-50 dB”, “50-60 dB”, and “60-70 dB”), and that the majority of time was spent in this range of sound levels (84.9%). This finding is consistent with Jensen and Nielsen’s (2005) observation that the mean (+/-1 sd) sound levels of all the listening category recordings fall between 50 and 80 dB SPL. In addition, Jensen and Nielsen (2005) pointed out that the presence of the participant's voice would significantly increase the overall sound level, which may help explain why the "Speech Only" environment was present in all six of the sound level categories (see Figure 12).

The overall sound level data can also be examined in terms of its breakdown into the four different listening environments of "Quiet", "Speech Only", "Speech in Noise", and "Noise Only". All six of the overall sound level ranges contain the three listening environments "Speech Only", "Speech in Noise", and "Noise Only". This indicates that the hearing aid user needs to listen in those three listening environments in a wide range of overall sound levels. However, as noted above, the user's own voice would have a significant effect on the overall level recorded. In addition, the between-subject variation was large for most of the listening environments within each sound level range, as shown in Table 8. Therefore, although this general pattern of behaviour in terms of overall sound level within each listening environment could be interesting to the clinician, the large between-subject variation limits the usefulness of the data.

In terms of clinical implications, the overall sound level data could be useful to the clinician as a starting point to troubleshoot problems. The finding that a similar amount of time is typically spent in the four sound level categories below 70 dB SPL could be helpful in clarifying common hearing aid user problems. For example, Harwell (2005) suggests that if a client was complaining of continued difficulty in noisy situations, but the breakdown of sound levels into listening environments indicated she rarely spent time in noisy situations, it may serve as a starting point for further questioning of whether she is avoiding those situations. If so, a noise program or a change in automatic directionality sensitivity may be warranted. However, as the between-subject variation for most of the listening environment data within each sound level range was large, this data is not as helpful in illustrating hearing aid user behaviour. The data with smaller standard deviations were those for “Speech Only” situations in the overall sound level ranges between 40 and 70 dB SPL. This indicates that the high proportion of “Speech Only” in these sound level ranges is likely to more accurately reflect hearing aid user behaviour.

4.4 Age Effect

The finding that there was no significant effect of age or its interaction with environment classification and microphone mode on the measure of time spent indicates that there is a similar breakdown of relative time spent in different listening environments and microphone mode for the participants aged between 50 and 89 years. Furthermore, since most of the pair-wise comparisons between the measures of time spent in different overall sound levels also failed to reach statistical significance, it appeared that age did not consistently affect time spent in different sound levels at least for participants aged between 50 and 89 years. This finding may have implications for the prescription of hearing aid features. Manufacturers tend to suggest more sophisticated hearing aid features for clients with more active lifestyles, and these clients may often be relatively younger people with many work and social commitments. This could lead to third party funding providers allocating funds based on the age of the client. However, the present finding of no age effect suggests differentiation based solely on age may not be warranted, at least for hearing aid users aged between 50 and 89.

4.5 Style Effect

The finding that instrument style did not affect time spent in different listening environments, microphone modes, and sound levels suggests that audiologists can be sure that the location of the hearing aid on the ear due to its style is not affecting the sound input to the hearing aid, or interpretation of the data logging information. Although there was a significant interaction between style and listening environment, closer examination of the data shows that for all styles the majority of time is spent in "Speech Only" situations, followed in order by "Quiet", "Speech in Noise" and "Noise Only" situations (see Figure 7). The result of significant interaction is probably due to the pair-wise comparison between "Quiet" and "Speech Only" situations for the BTE hearing aids not reaching statistical significance.

4.6 Limitations of the Study and Suggestions for Future Research

This study has several potential limitations. Firstly, the fifty-seven participants in this study were made up of 50 males and 7 females. Because of the high-end nature of the Oticon Syncro and the GN ReSound Metrix, many of the users of these hearing aids are those clients with third party funding due to work-related noise exposure. As this demographic is largely male, there is a paucity of females using these hearing aids. This inequality may affect the data in terms of generalisation. However, examination of the data for the two groups separately showed that "Speech Only" was the environment in which the majority of time was spent for both groups, and the average time spent in this environment was significantly different from the time spent in the other three environments for both the male and female data. In addition, there was no significant difference found between time spent in "Speech in Noise" and "Noise Only" situations for both the male and the female data (see Figure 7).

Therefore, the differences seen between the male and female data may be due to the small sample size of the female group. Further studies are needed to examine female hearing aid users to determine whether there is a gender difference in the measure of time spent in different listening environments.

Another potential limitation of the study is the status of the participants as new hearing aid users. This may also limit the data in terms of generalisation. However, as clients are always new users at some point, information on listening environments for this population may still be helpful. Further studies are needed using similar methodology to examine experienced hearing aid users to determine whether there is a difference in the measure of time spent in different listening environments.

In this study, the measurement period was up to nine weeks after the hearing aid fitting, with the data logging feature displaying information from the most recent 4 weeks. Some might argue that this early period is not an accurate measure of hearing aid use as a new wearer is likely to use their aid intermittently or incorrectly. However, Humes et al. (1996) reported that hearing aid usage in terms of objective measures of hours of use was fairly stable over time, particularly more than two weeks after fitting. This study examined listening situation rather than hours of use over two follow-up sessions. As no session effect was found for time spent in different listening situations, this suggests that the early measurement period is indicative of the overall hearing aid usage.

Another possible limitation of this study in terms of generalization is that only two manufacturers' hearing aids were included. However, data from the two different brands of hearing aids used were found to yield similar results, with both aids showing similar listening patterns as well as a significant time usage difference between listening situations. This finding suggests that the general listening pattern identified in this study is independent of the manufacturer of the hearing aid.

5 Conclusion

The overall pattern of the hearing aid users' behaviours, in terms of time spent in different listening environments, showed that the listening environments most often experienced by the hearing aid user were "Speech Only" situations, followed by "Quiet" situations and then by two situations with similar amounts of time usage, "Speech in Noise" and "Noise Only". The distribution of time spent in listening environments with noise present, i.e., "Speech in Noise" and "Noise Only" provides guidelines to clinicians regarding potential hearing aid user benefit from noise reduction algorithms and directional microphones. The microphone mode most often experienced by the hearing aid user was 'Surround' mode, followed in order by "Split" and "Full" directional modes. The result of no significant difference between ears for the time spent in each microphone may be useful to the clinician as it demonstrates that they may not be placing clients at a disadvantage by choosing a hearing aid without the ability to communicate between ears. The finding of no age effect on time spent in different listening environments, microphone modes or overall sound levels suggests hearing aid funding allocations based solely on age may not be warranted, at least for hearing aid users aged between 50 and 89. Further research using similar methodology to the present study is needed to investigate the pattern of hearing aid use of both female and experienced hearing aid users.

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