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The effects of expansion on objective and subjective benefit in hearing-impaired listeners

Ashley B. Hill
Louisiana State University and Agricultural and Mechanical College

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THE EFFECTS OF EXPANSION ON OBJECTIVE AND SUBJECTIVE BENEFIT IN HEARING-IMPAIRED LISTENERS

A Thesis

Submitted to the Graduate Faculty of the
Louisiana State University and
Agricultural and Mechanical College
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in

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Ashley B. Hill
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ABSTRACT

The present research involves two studies. Twenty hearing-impaired participants were divided into two groups depending on their audiometric data and binaurally fit with the Starkey Endeavour 3211 hearing instruments. Experiment I was designed to determine if the use of expansion technology affected objective and subjective benefit in hearing-impaired listeners. Probe microphone measures were obtained at 40, 50, and 60 dB SPL and with the speaker deactivated to ensure that the expansion feature was functioning. Listener performance was measured in quiet using the Connected Speech Test (CST) and in noise using the Hearing in Noise Test (HINT) at 40, 50, and 60 dB SPL with expansion activated and deactivated. Participants were also asked to participate in a subjective portion of the experiment. They filled out a rating form twice a day in two settings: quiet and in noise, with expansion activated and deactivated. Results indicated that expansion negatively affected user performance, but participants significantly preferred the feature.

Experiment II, very similar in design, examined expansion time constants and their effects on objective and subjective benefit in hearing-impaired listeners. Experiment II examined four different expansion time constants (128 ms, 512 ms, 2048 ms, 4056 ms) to determine their role on speech intelligibility in quiet and in noise with two levels of hearing-impaired subjects (one group was worse than the other). The CST and the HINT were administered at 65 dB SPL to determine listener performance. A similar subjective rating form was used in Experiment II. Participants were asked to rate the speed of the gain and/or reduction of gain in quiet and in noise while speaking and listening. Results indicated that as expansion time constants lengthened performance decreased. Results indicated that there was no preferred time constant and that as the time constant lengthened performance decreased.

CHAPTER I

INTRODUCTION

The present study examines expansion, a new feature in digital hearing instruments that was designed to reduce the gain given to low-level signals. There are two studies within this research. The first study examines the effects of expansion on objective and subjective benefit in hearing-impaired listeners. The second study investigates the effects of expansion time constants on objective and subjective benefit in hearing-impaired listeners.

Experiment I

Wide range compression hearing instruments provide reduced gain for high-level input signals and increased gain for low-level input signals (Johnson, 1993; Killion, 1996). In addition, input signal levels below the kneepoint of compression receive the maximum gain allowable by the hearing instrument in WDRC devices. Providing maximum gain for low-level signals may improve speech intelligibility by increasing the audibility of speech cues necessary for feature identification. However, providing maximum gain for low-level signals may also increase the audibility of low-level noises generated by the hearing instrument, thereby creating the complaint that WDRC hearing instruments are abnormally noisy when used in low-level environments (Ghent, Nilsson, & Bray, 2000; Venema, 1998).

Noise generated from within the hearing instrument typically originates form the microphone (Kuk, 2002) and approximates 20 dB in most modern devices (Sandlin, 2000). Since hearing instrument microphones are placed at the front end of the amplifier circuit, any noise generated by the microphone may be amplified by the hearing instrument and become audible to the listener (Kuk, 2002). Furthermore, increasing hearing instrument gain may also increase the audibility of the internal microphone noise and eventually become bothersome to the listener when in a low-level environment (Ricketts & Henry, 2002). The amplification of microphone and internal noise may also be particularly bothersome for listeners with hearing thresholds at or near normal for some frequency regions (Sandlin, 2000).

Vilchur (1978) observed that excessive gain of low-level inputs was an undesirable by-product of compression and suggested that a decrease in amplification for low-level inputs may combat this problem in hearing instruments. Expansion technology was designed to reduce the amount of amplification of low-level inputs, thereby resulting in reduced audibility of internal noise generated by the hearing instrument when listening in low-level environments (Kuk, 2002). Opposite to compression, expansion technology results in a reduction of hearing instrument gain when input signals levels are below a criterion input level known as the expansion kneepoint (Sandlin, 1999). Consequently, low-level input signals, such as microphone noise, receive reduced gain rather than maximum gain due to expansion technology (Ghent, Nilsson, & Bray, 2000).

Ghent, Nilsson, and Bray (2000) investigated the effectiveness of expansion technology with digital hearing instruments. Results demonstrated that expansion technology did indeed reduce the amount of gain given to low-level input signals; however, no attempt was made to determine if reducing the amplification of low-level input signals affected listener performance or preference (Ghent, Nilsson, & Bray, 2000).

Plyler (2002) examined the effects of expansion on user performance and preference in normal and hearing impaired listeners. Results indicated similar performance and preference in quiet and in noise with and without expansion. However, the author noted, that these results should be viewed with caution due to a small sample size (n=7) and the fact that subjects were not allowed to use the hearing instruments outside of the laboratory setting.

Research has demonstrated that reducing the gain given to low-level signals via expansion reduced the amplification of internal hearing instrument noise (Ghent, Nilsson, & Bray, 2000). However, what remains unclear is if reducing the amplification of low-level signals via expansion affects recognition of low-level speech in quiet and in low-level environments. What also remains unclear is if the use of expansion technology affects hearing instrument sound quality when utilized outside of the laboratory setting. Therefore, the purpose of Experiment I was to determine if expansion technology affected objective and subjective benefit in hearing-impaired listeners and if benefit with expansion was related to degree of hearing-impairment.

Experiment II

Attack and release times, also termed time constants, of wide dynamic range compression hearing instruments can have a very important affect on speech intelligibility and sound quality of a signal (Wang, 2001). The attack time is the time needed to activate the compression process for gain reduction when the input signal rises above a preset level known as the kneepoint or compression threshold. The release time is the time needed to deactivate the compression process for gain recovery when the input signal falls below the kneepoint or compression threshold (Wang, 2001). With a short attack time, the level of output signal is reduced quickly with a high input signal arrives. Likewise, with a short release time, the output signal quickly returns to the original level (Sandlin, 2000). Short attack and release times are advantageous, because amplification is quickly reduced when a loud transient sound is presented. However, short attack and release times can introduce temporal and spectral smearing and may potentially result in degraded intelligibility (Van Tasell, 1993). Implementing longer attack and release times may decrease spectral smearing; however, listeners may be subjected to excessive gain when a transient sound is presented (Sandlin, 2000). Long attack and release times also cause a lagging perception, making the signal sound delayed, which decreases speech intelligibility. As a compromise attack and release times are generally set between these two extremes (Sandlin, 2000).

There is a vast amount of published research concerning the length of compression time constants and their influence on hearing instrument user objective and subjective benefit; however, there is currently no research investigating the correlation between time constants and expansion. Therefore, the purpose of Experiment II is to determine the effects of expansion time constants on objective and subjective benefit for hearing-impaired listeners.

CHAPTER II

REVIEW OF LITERATURE

Mrs. Jones, a sixty-seven year-old woman, went to the audiologist for her fourth visit to get a step closer to what she referred to as “her monies worth”. The audiologist asked Mrs. Jones how her new hearing aids were working. They talked about how last weeks alterations: “Do you like what we did to the level of those loud sounds? How about the feedback, did that get better?” “Oh yes,” Mrs. Jones assured the audiologist, “they are working great and I would really like them, if you could fix one thing! When I am in a quiet room I hear a constant hum that sounds like I have my ear up to a seashell. Can you please get rid of that noise?”

Mrs. Jones complaint is a common criticism that dispensing audiologists encounter. The “humming” sound that she complained about was a series of low-level noises that the hearing instrument was detecting and giving maximum gain.

The present study examines expansion, a feature in digital hearing instruments that is offered to eliminate the gain given to low-level signals. There are two studies within this research. The first study examines the effects of expansion on objective and subjective benefit in hearing-impaired listeners while the second study examines the effects of expansion time constants on objective and subjective benefit in hearing-impaired listeners.

Internal and External Noise

Noise is an unavoidable by-product of hearing instruments. The noise associated with hearing aids has the potential to be bothersome to the hearing aid wearer (Lee & Geddes, 1998; Macrae & Dillon, 1996). Hearing instrument noise may originate from sources internal or external to the device.

External noises are generated in the environment and are external to the hearing instrument microphone (Sandlin, 2000). Low-level sounds in a quiet environment, such as a refrigerator or a computer running, are considered examples of external noise. Random movement of air molecules, in warm environments, is also a contributor of external noise. These air molecules, driven by thermal energy enter the microphone, displace the diaphragm, and go through the acoustic flow patterns of the microphone the same way an acoustical signal would (Valente, 1996).

Internal noise typically is generated from sources within the hearing instrument. Internal noise typically originates from the microphone of the hearing instrument (Kuk, 2002) and approximates 20 dB in most modern hearing instruments (Sandlin, 2000). Since hearing instrument microphones are placed at the front end of the amplifier circuit, any noise generated by the microphone may be amplified by the hearing instrument (Kuk, 2002). Consequently, increases in the hearing instrument gain may increase the audibility of the internal noise generated by the microphone to a level that is perhaps bothersome to a listener in a low-level environment (Ricketts & Henry, 2002). The amplification of microphone noise may also be particularly bothersome for listeners with hearing thresholds at or near normal for some frequency regions (Sandlin, 2000). Agnew and Block (1997) also found that the apparent pitch of internal microphone noise occurs in a low frequency region, where many people have sufficient hearing, thus making this noise more bothersome.

Internal noise is also generated in the resistances and semiconductors of the circuitry. These circuitry components create a noise voltage that, once amplified, may become audible to persons with sufficient low frequency hearing sensitivity (Sandlin, 2000). Consequently, increases in hearing instrument gain may increase the intensity of the internal noise generated by the resistances and semiconductors of the circuitry to a level that is perhaps bothersome to a listener in a low-level environment (Sandlin, 2000).

Expansion

Wide dynamic range compression (WDRC) has been largely successful at managing recruitment by reducing the discomfort of high-level stimuli while making low-level speech audible. Wide dynamic range compression hearing instruments provide reduced gain for high-level input signals and provide maximum gain for low-level input signals (Johnson, 1993; Killion, 1996). As a result, low-level input signals such as external and internal noises receive the maximum gain allowable by the hearing instrument. Generating maximum amplification of such low-level noises via WDRC can result in the complaint that the hearing instrument is abnormally noisy when listening in low-level environments (Ghent, Nilsson, and Bray, 2000).

Villchur (1978) observed that excessive amplification of low-level inputs was an undesirable by-product of compression and suggested that a decrease in amplification for low-level inputs may combat this problem in hearing instruments. Expansion technology was designed to reduce the amount of amplification of low-level inputs, thereby resulting in reduced audibility of internal and external noises when listening in low-level environments (Kuk, 2002). Opposite to compression, expansion technology results in a reduction of hearing instrument gain when input signal levels are below a criterion input level known as the expansion kneepoint (Sandlin, 1999). Consequently, low-level input signals receive reduced gain rather than maximum gain due to expansion technology (Ghent, Nilsson, and Bray, 2000).

Ghent, Nilsson, and Bray (2000) investigated the effectiveness of expansion technology in in-the-ear hearing instruments. Results demonstrated that expansion technology resulted in reduced amplification of low-level input signals; however, no attempt was made to determine if the reduced amplification of low-level input signals affected listener performance or preference.

Plyler (2002) examined the effects of expansion on user performance and preference in normal and hearing-impaired listeners. Listener performance was evaluated in quiet and in noise at 40 dB SPL, while listener preference was evaluated, by asking each subject to determine which condition they would select if they had to wear a hearing aid. Results indicated similar performance and preference in quiet and in noise with and without expansion. Although group data did not reveal significant performance differences when utilizing the expansion feature, performance differences were evident in some hearing-impaired individuals. Examination of individual hearing-impaired data suggested that successful utilization of expansion technology may be related to audiometric pure tone average.

The Plyler (2002) study represented the first known investigation examining the effects of expansion on user performance and preference. However, findings from the Plyler (2002) study must be viewed with caution due to several design constraints. For example, the inclusion of normal hearing subjects may have resulted in ceiling effects that prohibited the detection of an expansion effect. Also, all testing was conducted at the expansion kneepoint of 40 dB SPL. Therefore, it is possible the effects of expansion were minimal because the stimuli were not presented at levels sufficiently below the kneepoint of expansion. In addition, the seven hearing-impaired subjects used in the study were fitted unilaterally and were not allowed to use the hearing instruments in their daily lives. The use of such a small sample of hearing-impaired listeners (N=7) may have resulted in insufficient power to adequately evaluate the effects of expansion.

Rationale: Experiment I

Expansion, a relatively new technology, was designed to eliminate the amplification given to low-level internal and external noises. Ghent, Nilsson, and Bray (2000) examined expansion technology and determined that expansion successfully reduced the gain given to low-level inputs; however, their study did not examine user performance or preference. Plyler (2002) expanded Ghent, Nilsson, and Bray's study, examining user preference; however, his study had several design constraints. The lack of research conducted concerning expansion led to the design of the present study. The first purpose of the study was to examine the effects of expansion on user performance and preference using subjective and objective data.

Reducing the amplification of low-level signals may reduce the audibility of low-level, high frequency speech cues necessary for accurate speech recognition. Consequently, expansion technology may negatively impact the recognition of low-level speech in quiet and in noise when input signals are at or below the kneepoint of expansion. In addition, although expansion technology has been shown to reduce the amplification of low-level signals (Ghent et al., 2000), what remains unclear is if the use of expansion technology actually results in a subjective improvement in sound quality for hearing instrument users. Therefore, the purpose of Experiment I was to determine if the use of expansion technology affected objective and subjective benefit in hearing-impaired listeners.

<u>Time Constants</u>

Attack and release times, also termed time constants, of wide dynamic range compression instruments can have a very important effect on speech intelligibility and sound quality of a signal (Wang, 2001). Attack and release times are two dynamic characteristics that describe the output envelope after a change in the input envelope (Bentler and Nelson, 1977). The attack time is the time needed to activate the compression process for gain reduction when the input signal rises above a preset level known as the kneepoint or the compression threshold. The release time is the time needed to deactivate the compression process for gain recovery when the input signal falls below the kneepoint or compression threshold (Wang, 2001). ANSI S3.22 (1996) specifically defines the duration of the attack and release times as the time necessary for the circuit to stabilize within 3 and 4 dB of the steady-state value used to activate the compression (90 dB SPL for attack time) and release from compression (55 dB SPL for release time).

Many studies have been published on the possible effects of various attack and release times on speech intelligibility, sound quality, and their affect on the hearing instrument user (Wang, 2001). Research has determined that if time constants are too short/fast, the gain will fluctuate rapidly and may cause a “pumping” perception perceived by the listener. However, if the time constants are too long/slow, the compression will cause a lagging perception on the part of the listener (Kuk, 2002). Both of which can adversely affect speech perception and cause annoyance (Wang, 2001). Kuk, (2002) compares hearing instrument time constants to a television broadcast in which the sports announcer is talking and the background noise is changing in intensity over time. When a score is made and the sport fans suddenly increase the intensity of their cheers, the background noise increases in intensity. It may take a short time for the compression of the audiovisual equipment to attack and reduce the gain of the noise. This also temporarily reduces the gain for the announcer’s voice. When the cheering stops, it takes some time for the system to release from compression. The level of the announcer’s voice takes some time to return to a normal level. Hearing instrument users are faced with this phenomenon every time there is a large fluctuation in the input signals around them. Most attack and release times are set to achieve a compromise between the two extremes (Sandlin, 2000).

Short Attack and Release Times

Hearing instrument circuits built with short attack and release times are known as syllabic compression circuits. With a short attack time, the level or output signal is reduced quickly when a high input signal arrives. A short attack time is thought to be more advantageous because the hearing instrument must reach the stabilized compressed level quickly enough to deal with transient noises such as a door slamming (Wang, 2001). In syllabic compression, the attack and release times are specifically intended to be shorter than the duration of typical speech syllable, which is about 200 to 300 ms (Hickson, 1994). Short attack times allow the hearing instrument to reduce the gain for the peaks of more intense speech (usually the vowel sounds). This provides more uniformity in the intensity of ongoing speech syllables (Kuk, 2002). Research has determined that short attack times also decrease annoyance and/or distortion (Blesser, 1969; Davis et al., 1947; Edgardh, 1952; Lynn and Carhart, 1963; Schweitzer and Causey, 1977). Braida (1979) reported that manufactures often chose an attack time of <1ms for these reasons.

Likewise, with a short release time, the output signal quickly returns to the original level (Sandlin, 2000). Studies have shown that a shorter release time in the high-frequency range may improve the perception of short-duration, low amplitude consonants and give additional formant information, possibly resulting in maximizing speech intelligibility (Lanrence et. Al, 1983). Research has also reported that short release times also help maximize speech intelligibility in noise (Jerivall and Lindblad, 1978; Kretzinger and Young, 1960; Schweitxer and Causey, 1977). Burnett and Schweitzer (1977) measured release times on a large sample of hearing instruments and found that although release times ranged from less than 5 ms to 1,120 ms over half of the hearing instruments evaluated had release times of 50 ms or less. Past literature has suggested that an appropriate release time may lie between 20 and 150 ms in order to avoid low-frequency component distortion (Blesser, 1969; Carter, 1964).

However, if attack and release times are too short and used in conjunction, they can be associated with complaints from hearing instrument users that the intended signal sounds "breathy" or like it is "pumping". This pumping sensation is due to the rapid fluctuations in the hearing instrument gain and can cause high distortion (Johnson, 1993). Johnson (1993) also reveals in his study that fast attack and release times may be associated with the echo/contour smearing effect. He found that this could cause reverberation to be amplified proportionately more than speech, which would allow environmental noise to fill in the inersyllabic gap thus smearing the contour of the speech. This smearing of the contour of the speech spectrum thus affects the consonant/vowel relationship in the intended signal and the signal to noise ratio (Johnson, 1993). Van Tasell (1993) expanded previous studies and determined that the temporal and spectral smearing, caused by short attack and release times, resulted in degraded speech intelligibility.

Long Attack and Release Times

Hearing instrument circuits built with long time constants are known as automatic volume control (AVC) circuits. Long time constants are usually more than 150 ms and may be as long as several seconds. Long attack and release times prevent the hearing instrument from responding to rapid fluctuations of sound input, reducing the need for the listener to adjust the volume control, hence the name of the circuitry. Implementing longer attack and release times has been used to decrease spectral smearing; however, when the attack and release times are lengthen listeners may be subjected to excessive gain when a transient sound is presented (Sandlin, 2000). Hearing instrument users also complain that they perceive a lag in the signal when longer attack and release times are implemented in their hearing instrument. This can also decrease their speech intelligibility and be an annoyance to the hearing instrument user. However, conflicting research has shown that longer release times in the low-frequency regions of a signal may reduce the upward spread of masking improving the speech intelligibility for the hearing-impaired listener (Dreschler and Plomp, 1985; Laurence, Moore, & Glasberg, 1983). Currently, most hearing aid manufactures use a combination of the extremes.

Rationale: Experiment II

The importance of attack and release times and their influence in speech intelligibility has been documented. Jerivall and Lindblad (1978) reported that short release times help maximize speech intelligibility in quiet and in noise. However, the increase in speech intelligibility may come at a cost; many hearing instrument users complain that they perceive the signal as "pumping". Longer time constants alleviate the "pumping" perception, but in return may cause a "lagging" perception. Research examining AVC, or longer time constants has shown that longer release times in the low-frequency regions of a signal may too improve speech intelligibility (Dreschler and Plomp, 1985; Laurence, Moore, & Glasberg, 1983).

There is a vast amount of published research concerning the length of time constants and their influence on hearing instrument user objective and subjective benefit with traditional compression; however, there is currently no research investigating the correlation between time constants and expansion. Therefore, the purpose of Experiment II was to examine the effects of expansion time constants on objective and subjective benefit in hearing-impaired listeners.

CHAPTER III

METHODOLOGY

The present research has two studies involved. Experiment I was designed as an experimental, parametric study that examined the effects of expansion on objective and subjective benefit in hearing-impaired listeners. This study examined expansion activated versus deactivated at three different stimulus levels (40, 50, and 60 dB) for 2 groups of hearing-impaired listeners. Objective data was measured in quiet using the Connected Speech Test (CST) and in noise using the Hearing in Noise Test (HINT). All testing was randomized to ensure the validity of the study. Participants were also asked to participate in a subjective portion of the experiment. They filled out a rating form twice a day in two settings: quiet and in noise, with expansion activated and deactivated. Again, validity was ensured, by blinding the subjects; they had to select memory 1 versus memory 2 of their hearing instruments, instead of expansion on versus off.

Experiment II, very similar in design, examined expansion time constants and the effects on objective and subjective benefit in hearing-impaired listeners. Again, an experimental, parametric study was implemented. This study examined four different expansion time constants to determine their role on speech intelligibility in quiet and in noise with two levels of hearing impaired subjects (one group was worse than the other). The CST and the HINT were used to collect the objective data. A similar subjective rating form was used in Experiment II, as well. Participants were asked to rate the speed of the gain and/or reduction of gain in quiet and in noise while speaking and listening. All testing was randomized and the four time constants were randomly set as different memory settings on the hearing instruments.

Participants

Twenty participants were included in this experiment. The participants were equally chosen for two groups [Group 1 (45-82 years old) and Group 2 (31-88 years old)]. The criteria for inclusion in Group 1 included: (i) sensorineural hearing impairment with no more than a 15 dB HL difference in pure tone thresholds at any octave frequency from 250 through 8000 Hz between ears (ANSI S3.6-1996); (ii) normal appearance of ear canal and pinna; (iii) normal tympanograms bilaterally; (iv) no air-bone gaps greater than 10 dB; (v) previous hearing aid experience; and (vi) two adjacent hearing thresholds better than 40 dB HL from 250 through 1000 Hz. The inclusion criteria for Group 2 differed from that of Group 1 in one aspect: (i) two adjacent hearing thresholds worse than 40 dB HL from 250 through 1000 Hz (Figure 1). All qualifications and experimental tests were conducted in a sound-treated examination room (Industrial Acoustic) with ambient noise levels suitable for testing with ears uncovered (ANSI S3.1-1991).

Stimuli

The Hearing in Noise Test (HINT, House Ear Institute) and the Connected Speech Test (CST) served as the stimuli. The CST (Cox, Alexander, & Gilmore, 1987; Cox, Alexander, Gilmore, & Pusakulich, 1988) is a test of speech recognition for everyday speech presented at a fixed SNR. The CST consisted of 24 pairs of speech passages produced conversationally by a female speaker. It should be noted that CST used in this study was modified and presented without noise. All passages were randomly selected without replacement. The HINT consisted of 25 lists of 10 English sentences produced by a male speaker. The HINT was developed as a measure of speech recognition in noise with and without spatial separation from the speech source. Normative data have been collected for listeners with both normal and impaired hearing (Nilsson, Gellnet, Sullivan, & Soli, 1992; Nilsson, Soli, & Sullivan, 1994).

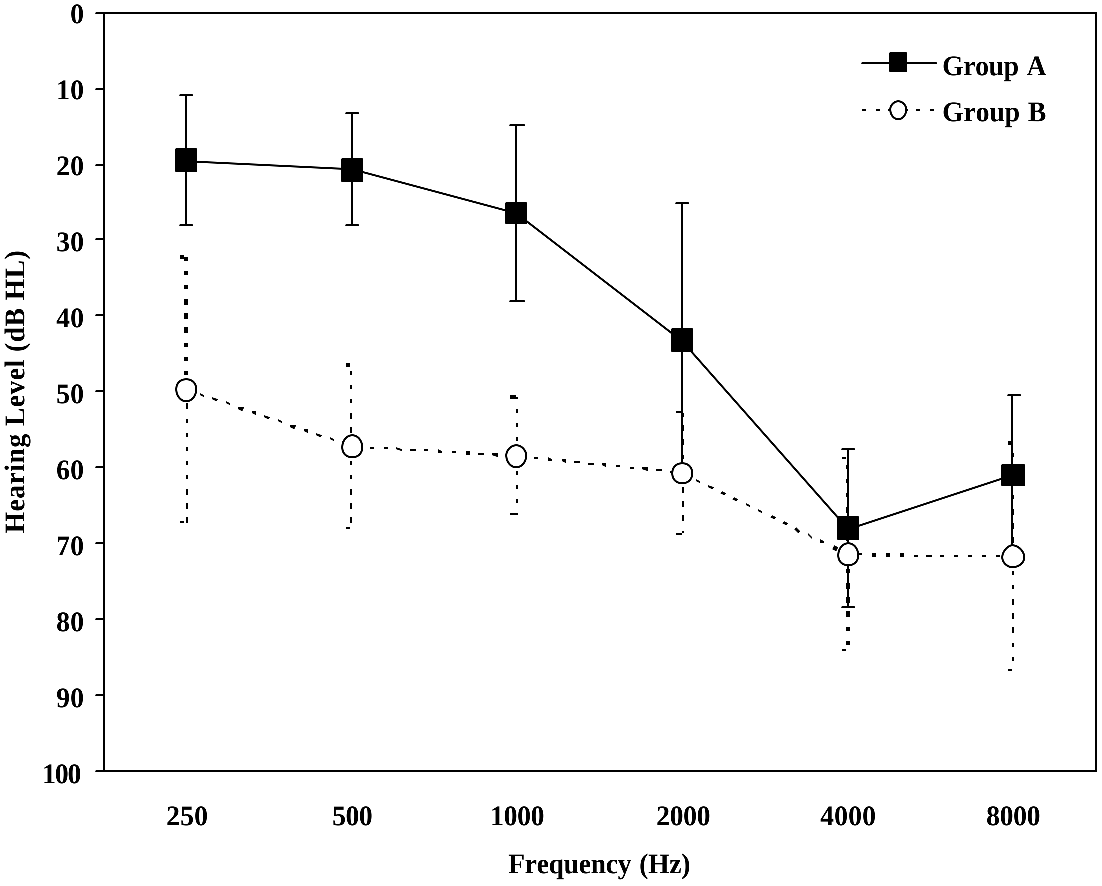


Figure 1. Average audiometric threshold data for hearing-impaired participants

An adaptive presentation was utilized to determine the sentence reception threshold in terms of signal-to-noise ratio for each participant using 10-sentence blocks. All blocks were randomly selected without replacement.

All speech stimuli and background noise were produced by a compact disc player and routed through a two-channel diagnostic audiometer (GSI-61) to a loudspeaker located in the sound treated examination room. The output levels of the speech stimuli and background noise were calibrated at the vertex of the listener and were checked periodically throughout the experiment.

Hearing Instruments

Prior to experimental testing, qualified participants were fit binaurally with digital in-the-ear hearing instruments (Starkey Endeavour 3211). The expansion kneepoint was set at 50 dB SPL at each frequency. The hearing instruments utilized in this study were multiple memory devices; however, the participants were unaware of which expansion condition (memory) they were using at all times.

Hearing Instrument Fitting

The digital hearing instruments were programmed for each participant using the participant's audiometric information and the desired sensation level fitting strategy. Uncomfortable loudness level (UCL) data were measured and utilized for all participants. Binaural probe microphone measures were conducted on each subject to verify match to NAL-R target (+/- 6 dB from 500-4000 Hz) using a swept pure tone at 65dB SPL. Probe microphone measures were also made with the loudspeaker deactivated for each test condition (expansion on and expansion off) and in the unaided condition to verify appropriate functioning of the expansion feature (Mueller, 2001). Probe microphone measurements were then made binaurally using input signal levels of 40, 50, and 60 dB SPL with the expansion feature activated and with the expansion feature deactivated. (Note: all noise suppression features were deactivated for the entire experiment).

The probe microphone system measurements consisted of 65 data points measured in 1/12th octave steps over a frequency range of 200 Hz to 8000 Hz. Data for output levels at the tympanic membrane in the eight conditions stored in the Audioscan RM500 were downloaded to a personal computer for subsequent data analysis.

The digital hearing instruments were programmed to have two settings. Each participant had one setting in which expansion was activated and one with expansion deactivated, while all the remaining parameters were held constant.

Experiment I: Expansion On vs. Expansion Off

Objective Evaluation

The first purpose of Experiment I was to objectively evaluate listener performance in quiet and in noise for each expansion condition. Two memories of the digital hearing instruments were programmed for each participant in Experiment I. All fitting parameters of memory one, were identical to all fitting parameters of memory two; however, expansion was activated in only one of the two memories. Therefore, each hearing instrument had one memory in which expansion was activated and one memory in which expansion was deactivated; however, all other fittings parameters were held constant across the two memories.

As mentioned previously, expansion technology is designed to minimize the internal microphone and circuit noise that results from amplification of low-level input signals. Therefore, all speech stimuli were presented at levels representative of low-level speech to ensure that portions of the speech spectra were below the expansion kneepoint for the two experimental conditions (expansion on and expansion off).

Speech stimuli were presented at 40, 50, and 60 dB SPL for the two experimental conditions (expansion on and expansion off). All performance testing was conducted with the subject seated 1 meter from the loudspeaker located at 0-degree azimuth in the sound treated room. Performance in quiet was evaluated using the CST and performance in noise was evaluated using the HINT. It should be noted that the HINT protocol utilized in the present study reflected a slight modification of the original HINT protocol in that noise levels were varied and speech levels were fixed. This protocol variation ensured that noise levels were maintained below the kneepoint of expansion when using the 40 dB SPL signal. Prior to data collection, an experimental schedule was generated for each subject listing a completely randomized assignment for expansion condition, CST passage, and HINT sentence list.

Subjective Evaluation

The second purpose of Experiment I was for listener's to subjectively evaluate hearing instrument performance in quiet and in noise for each expansion condition. Each subject utilized both hearing instruments for a ten-day trial period and was asked to complete a daily subjective evaluation of each expansion condition (Appendix A). For each memory, participants were asked to rate their satisfaction regarding the amount of background noise reduction they received in two environments: in quiet and in everyday low-level listening environments. Participants were asked to subjectively evaluate the expansion conditions two times a day for ten days, therefore, each participant rated each expansion condition a total of twenty times for each listening environment.

Experiment II: Time Constants

Hearing Instrument Fitting

The digital hearing instruments were programmed to have four settings. Expansion was activated and all parameters were held constant only varying the expansion time constants.

Attack and release times were the same for each of the four time constants: 128ms, 512ms, 2094ms, and 4096ms. The four time constants were randomized for each participant.

Objective Evaluation

The first purpose, of the second phase of the experiment, was to evaluate listener performance in quiet and in noise for each expansion time constant. Speech stimuli were presented at 65 dB SPL (average conversational speech level) for the four varying time constants: 128ms, 512ms, 2094ms, and 4096ms. A 6 second pause was utilized between each speech stimuli to ensure that expansion was activated. All performance testing was conducted with the subject seated 1 meter from the loudspeaker located at 0-degree azimuth in the sound treated room. Performance in quiet was evaluated using the CST and performance in noise was evaluated using the HINT. Prior to data collection, an experimental schedule was generated for each participant condition, CST passage, and HINT sentence list.

Subjective Evaluation

The second purpose, of the second phase of the experiment, was to determine the preferred expansion time constant. Participants wore both hearing instruments for a second ten day trial period and were asked to complete a subjective evaluation. Participants evaluated and rated their satisfaction with the speed of background noise reduction and/or gain for each of the four settings. Ratings were completed in quiet and in general listening environments twice a day, while they listened to themselves speak and listened to their television. Participants rated their satisfaction with the speed of background noise reduction while listening to their own voice stop and by listening to their television and muting it. They were also asked to rate their satisfaction with the speed of background noise/speech gain increase going from quiet to listening to their own voice start and the television as the volume resumed.

CHAPTER IV

RESULTS

Experiment I: Expansion On vs. Expansion Off

Probe Microphone Measures

Binaural probe microphone measures obtained with the loudspeaker deactivated were averaged across ears for the twenty subjects for the unaided condition and for the two expansion conditions to verify appropriate functioning of the expansion feature (Figure 2). Mean in-situ levels were calculated for the unaided condition and for each expansion condition by averaging the in-situ levels at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. The mean in-situ level was 19.6 dB SPL for the unaided condition, 25.7 dB SPL for the expansion on condition and 32.4 dB SPL for the expansion off condition. Results of a paired samples t-test demonstrated that the mean in-situ levels were significantly greater for the expansion off condition than the expansion on condition when the loudspeaker was deactivated [t (19) = 8.158; p<.05].

Binaural probe microphone measures obtained at 40, 50, and 60 dB SPL were also averaged across ears for the twenty participants for each expansion condition (Figures 3-5). A mean in-situ level was then calculated for each expansion condition at each intensity level by averaging the in-situ levels at 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Results of a paired samples t-test demonstrated that the mean in-situ levels were significantly greater for the expansion off condition than the expansion on condition when using a 40 dB SPL input signal [t (19) = 6.513; p<.05].

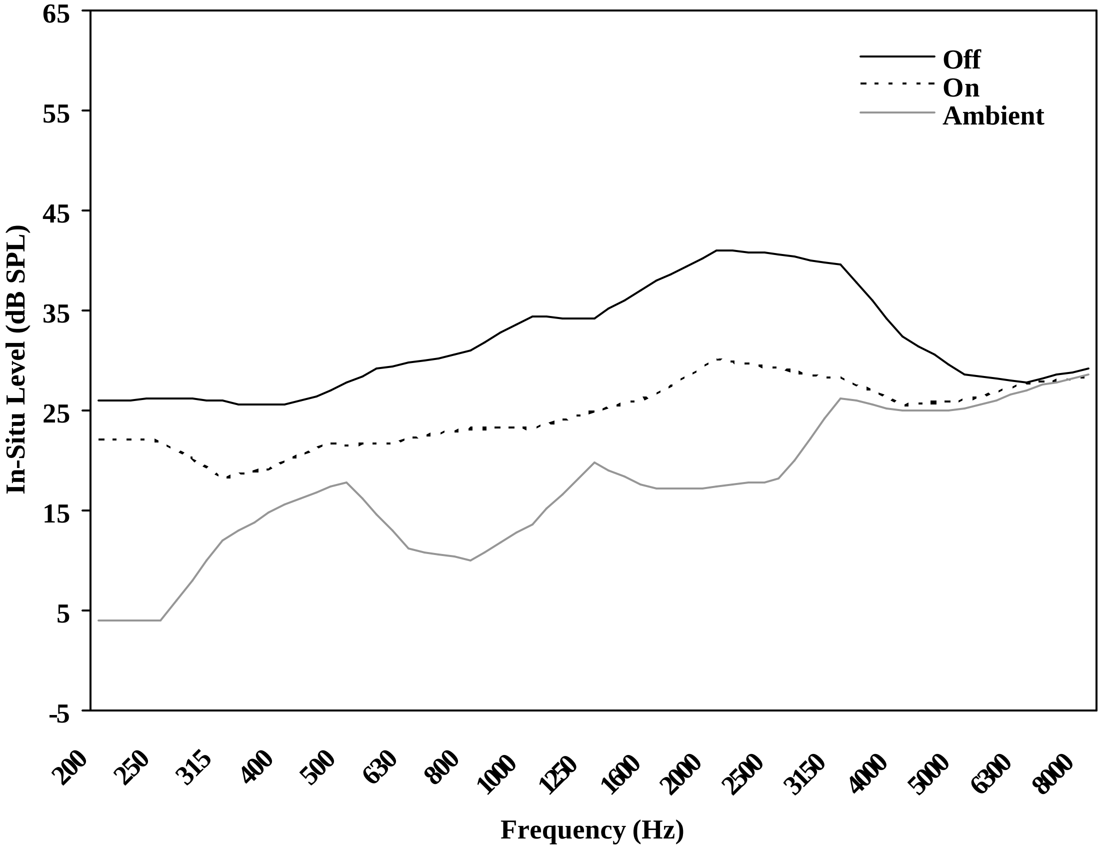


Figure 2. Average probe microphone measurements for the hearing with no signal

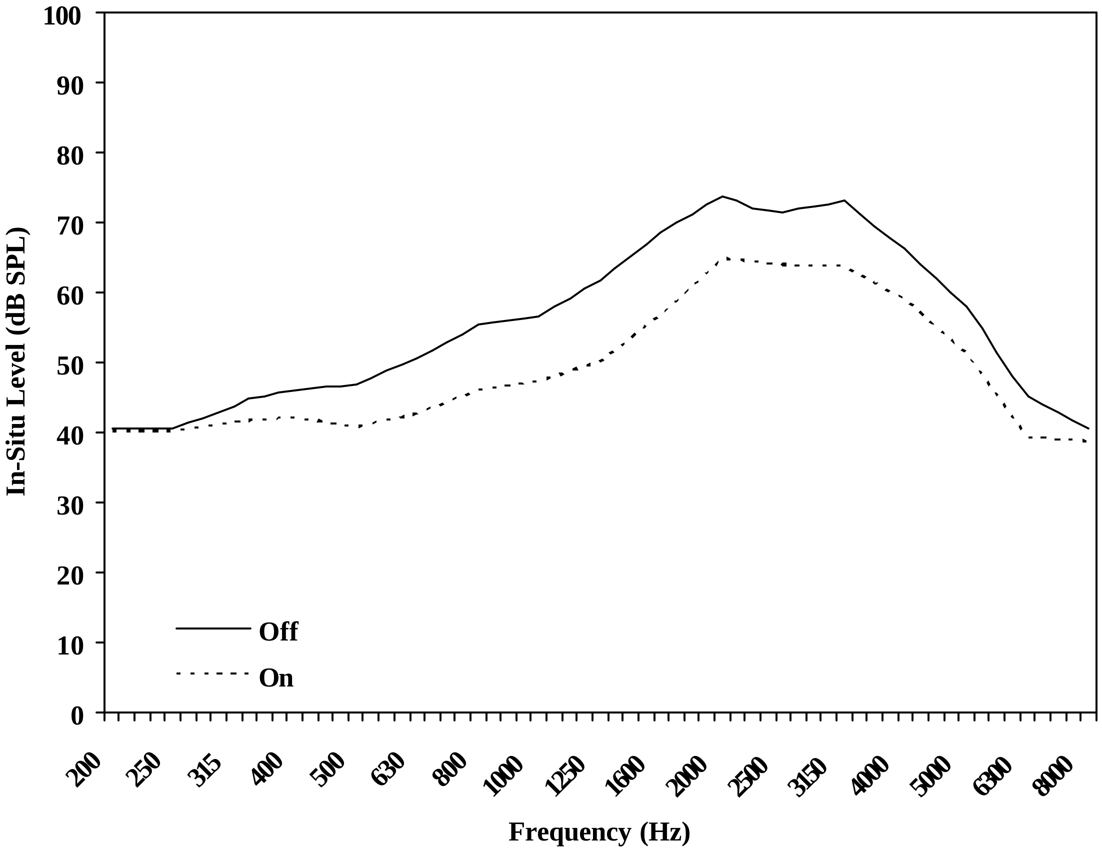


Figure 3. Average probe microphone measurements for the hearing instruments with a 40 dB SPL signal

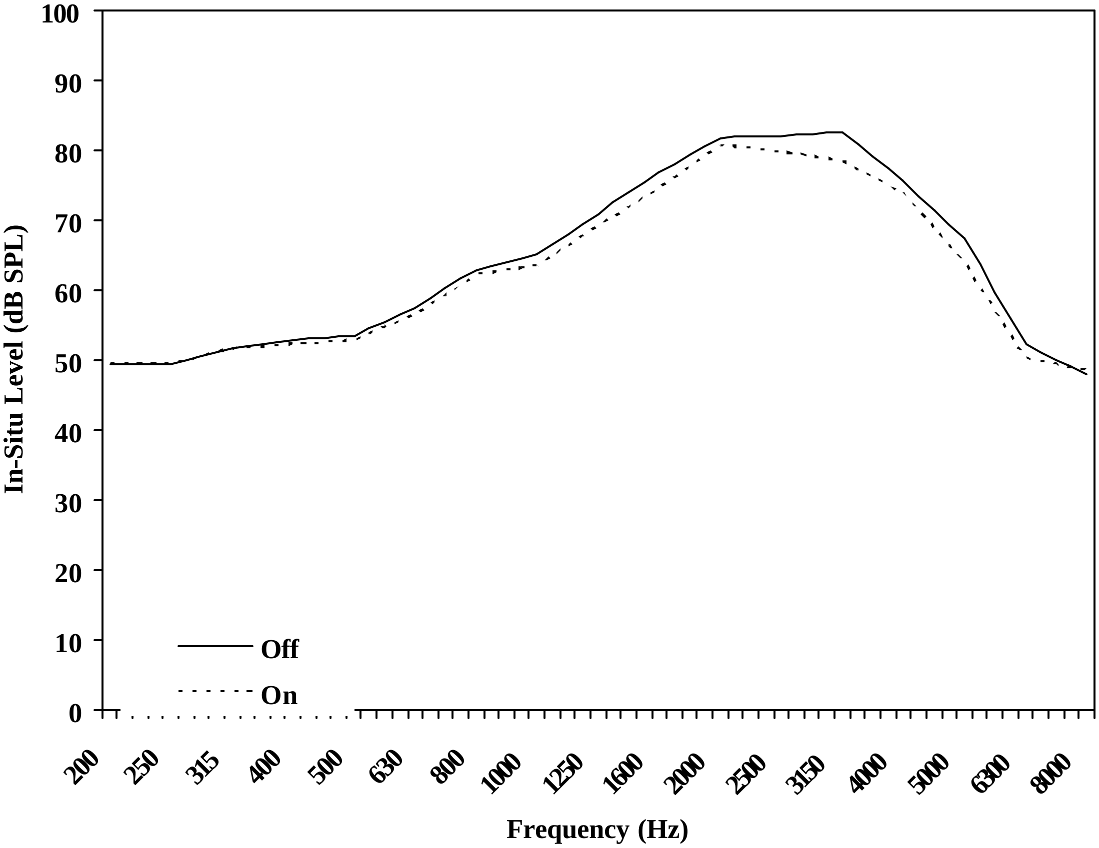


Figure 4. Average probe microphone measurements for the hearing instruments with a 50 dB SPL signal

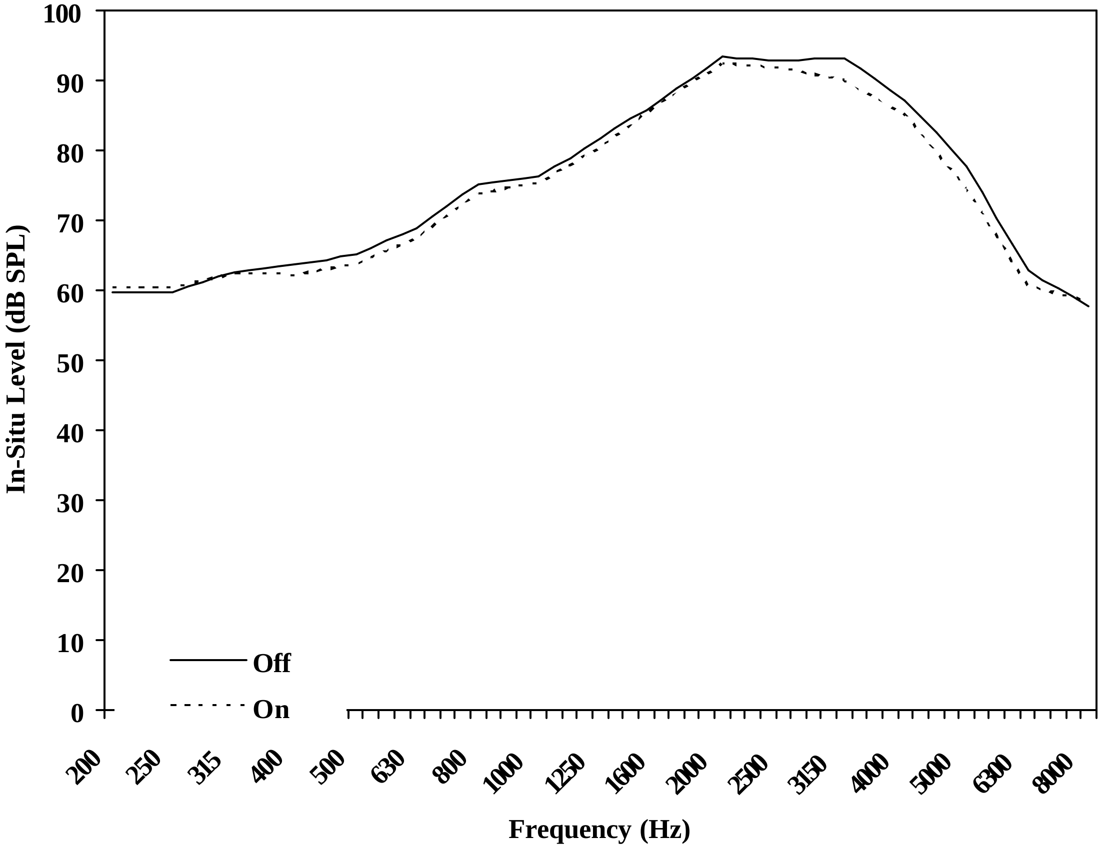


Figure 5. Average probe microphone measurements for the hearing instruments with a 60 dB SPL signal

Results further demonstrated that the mean in-situ levels were similar for each expansion condition when using the 50 dB SPL input signal [t (19) = 1.096; p>.05] and the 60 dB SPL input signal [t (19) = 1.451; p>.05]. Results of the probe microphone testing indicated that the expansion feature was functioning appropriately for each hearing instrument utilized in the present study.

Objective Evaluation

The first purpose of Experiment I was to objectively evaluate listener performance in quiet and in noise for each expansion condition. The Connected Speech Test (CST) was conducted at three levels (40, 50, and 60 dB SPL) for each participant to assess performance in quiet. CST scores were then averaged across the twenty subjects for each expansion condition and each intensity level (table 1, Figure 6).

A three-way analysis of variance was performed to evaluate the effects of expansion, intensity level, and hearing sensitivity on performance in quiet. The dependant variable was CST score. The within-subject factors were expansion with two levels (off and on) and intensity level with three levels (40, 50, and 60 dB SPL). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effects for expansion [F(1,18) = 22.064, p<.05], intensity level [F(1,18) = 91.852, p<.05], and for group [F(1,18) = 77.586, p<.05]. Pairwise comparisons (Bonferroni) conducted to investigate the main effect for level indicated significant performance differences between all intensity levels tested.

The three-way analysis of variance also revealed a significant intensity level by group [F(1,18) = 7.692, p<.05] and intensity level by expansion [F(1,18) = 7.148, p<.05] interaction (table 1). A paired samples t-test was conducted to further investigate the intensity level by expansion interaction.

Table 1. Connected Speech Test means and standard deviations for Experiment I.

Group	Level (dB SPL)	Expansion On	Expansion Off
A	40	44.6 *(17.5)*	66.8 *(24.8)*
	50	80.4 *(13)*	87.8 *(13)*
	60	95.4 *(6.4)*	95.8 *(5.1)*
B	40	1.6 *(2.2)*	8 *(11.3)*
	50	20 *(14.8)*	35.8 *(22.2)*
	60	66 *(21.5)*	68.6 *(23.4)*

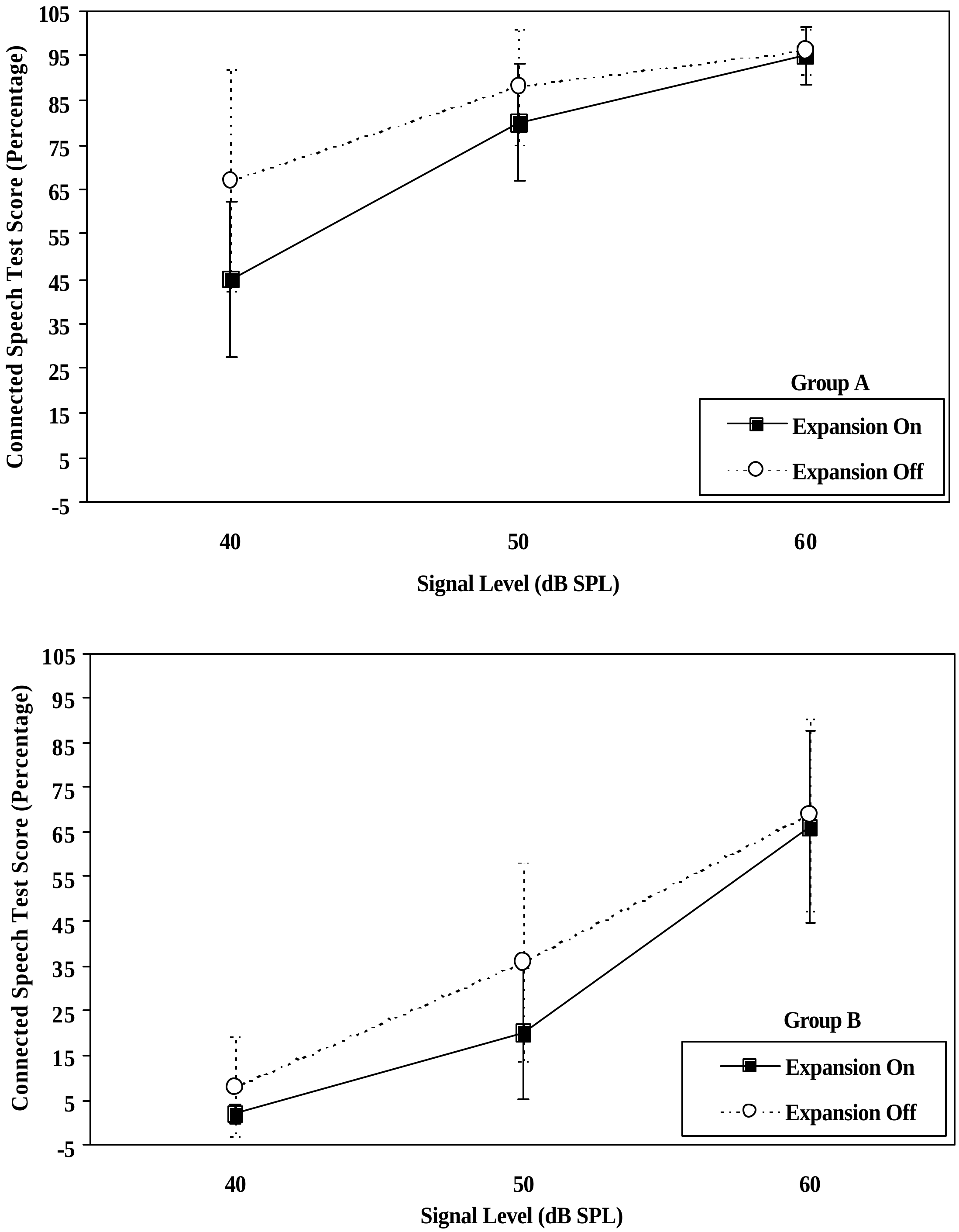


Figure 6. Average CST scores for 40, 50, and 60 dB SPL with expansion activated and deactivated.

Results indicated that performance in quiet was significantly poorer for the expansion on condition than the expansion off condition when using the 40 dB SPL input signal [t (19) = -3.574; p<.05] and the 50 dB SPL input signal [t (19) = -4.805; p<.05]. Results further demonstrated that performance in quiet was similar for each expansion condition when using the 60 dB SPL input signal [t (19) = -2.03; p>.05].

Results of testing in quiet indicated that performance improved as intensity level increased and that listeners with less hearing-impairment performed significantly better than listeners with more severe hearing-impairment. Results further indicated that listeners performed significantly better in quiet when the expansion feature was deactivated and that activation of the expansion feature significantly reduced listener's performance in quiet when the input signal level was at or below the kneepoint of expansion.

The Hearing in Noise Test (HINT) was conducted at three levels (40, 50, and 60 dB SPL) for each subject to assess performance in noise. HINT scores were then averaged across the twenty participants for each expansion condition and each intensity level (table 2, Figure 7). A three-way analysis of variance was performed to evaluate the effects of expansion, intensity level, and hearing sensitivity on performance in noise. The dependant variable was HINT score. The within-subject factors were expansion with two levels (off and on) and intensity level with three levels (40, 50, and 60 dB SPL). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effects for expansion [F(1,18) = 35.882, p<.05], intensity level [F(1,18) = 65.015, p<.05], and for group [F(1,18) = 17.314, p<.05]. Pairwise comparisons (Bonferroni) conducted to investigate the level main effect indicated significant performance differences between all intensity levels tested. The three-way analysis of variance also revealed a significant intensity level by expansion [F(1,18) = 11.781, p<.05] interaction (table 3).

Table 2. Hearing in Noise Test means and standard deviations for Experiment I.

Group	Level (dB SPL)	Expansion On	Expansion Off
A	40	14.2 *(4.4)*	9.9 *(5.2)*
	50	7.2 *(2.3)*	5.9 *(3.2)*
	60	-0.4 *(2.7)*	-0.1 *(2.6)*
B	40	20.7 *(7.7)*	18.3 *(7.4)*
	50	14.7 *(6.2)*	12.6 *(5.6)*
	60	7.7 *(3.6)*	7.2 *(4.2)*

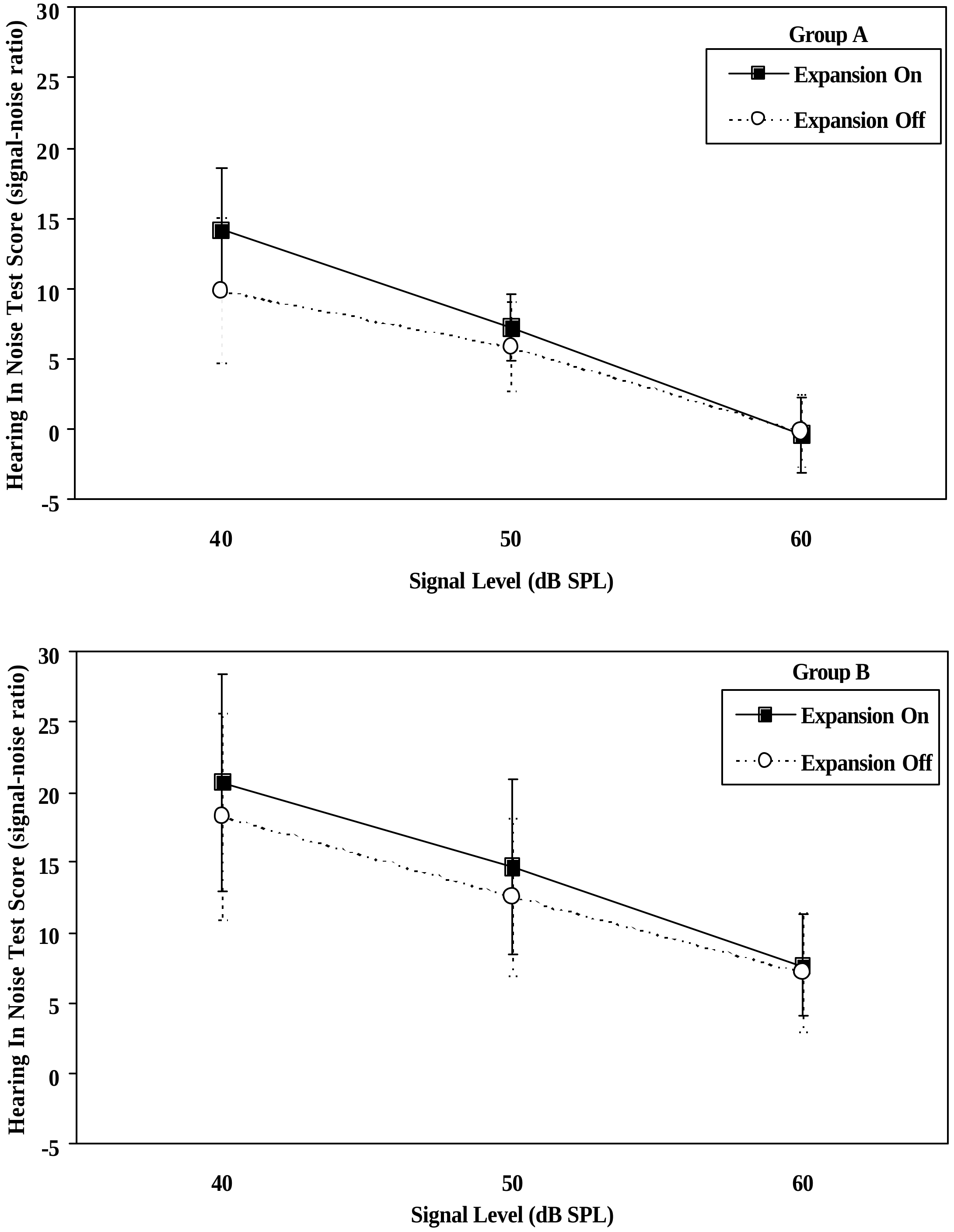


Figure7. Average HINT scores at 40, 50, and 60 dB SPL with expansion activated and deactivated for Experiment I

Table 3. Connected Speech Test means and standard deviations for Experiment II.

Group	Expansion Time Constant (ms)	Mean	Standard Deviation
A	128	97.2	3.1
	512	94.6	6.2
	2048	93.8	6.1
	4056	90.4	10.1
B	128	84.2	19.6
	512	83.2	19.6
	2048	78.3	20.2
	4056	71.4	22.2

A paired samples t-test was conducted to further investigate the intensity level by expansion interaction. Results indicated that performance in noise was significantly poorer for the expansion on condition than the expansion off condition when using the 40 dB SPL input signal [t (19) = 5.091; p<.05] and the 50 dB SPL input signal [t (19) = 3.955; p<.05]. Results further demonstrated that performance in noise was statistically similar for each expansion condition when using the 60 dB SPL input signal [t (19) = .309; p>.5].

Results of testing in noise indicated that performance improved as intensity level increased and that listeners with less hearing-impairment performed significantly better than listeners with more severe hearing-impairment. Results further indicated that listeners performed significantly better in noise when the expansion feature was deactivated and that activation of the expansion feature significantly reduced listener performance in noise when the input signal level was at or below the kneepoint of expansion.

Subjective Evaluation

The second purpose of Experiment I was to obtain subjective evaluations of hearing instrument performance in quiet and in noise for each expansion condition. Each participant utilized both hearing instruments for a ten-day trial period and completed a daily subjective evaluation of each expansion condition (Appendix A). For each expansion condition, participants were asked to rate their satisfaction regarding the amount of background noise reduction they perceived in two environments: in quiet and in everyday low-level environments.

From the data collection phase, it was obvious that some individuals felt the expansion feature provided an insufficient amount of noise reduction (rating = 1 or 2) whereas other listeners felt the expansion feature provided an excessive amount of noise reduction (rating = 5 or 4). Both of these instances were viewed as ratings of dissatisfaction with the amount of noise reduction provided by the expansion feature. In order to evaluate the expansion feature in terms of satisfaction versus dissatisfaction, individual satisfaction ratings of 4 or 5 were recoded to ratings of 2 or 1 respectively to simply reflect dissatisfaction with the expansion feature. Individual satisfaction ratings were then averaged across the ten days and across the twenty subjects for each expansion condition and each listening environment (Figures 8 & 9).

A two-way analysis of variance was performed to evaluate the effects of expansion and hearing sensitivity on satisfaction ratings in quiet. The dependant variable was mean satisfaction rating. The within-subject factor was expansion with two levels (off and on). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effect for expansion [F(1,18) = 8.069, p<.05]. However, main effects for group [F(1,18) = 0.246, p>0.05], and for the expansion by group interaction [F(1,18) = 0.628, p>.05] were not significant. These results indicated that activation of the expansion feature significantly improved satisfaction ratings in quiet for listeners in each group.

A two-way analysis of variance was also performed to evaluate the effects of expansion and hearing sensitivity on satisfaction ratings in everyday low-level environments. The dependant variable was mean satisfaction rating. The within-subject factor was expansion with two levels (off and on). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effect for expansion [F(1,18) = 38.736, p<.05] and for the expansion by group interaction [F(1,18) = 11.231, p<.05]. However, main effects for group [F(1,18) = .047, p>.05] were not significant. These results indicated that activation of the expansion feature significantly improved satisfaction ratings in everyday low-level environments. Results further indicated that listeners with less hearing-impairment perceive a larger satisfaction increase when using expansion in low-level environments than listeners with more severe hearing-impairment.

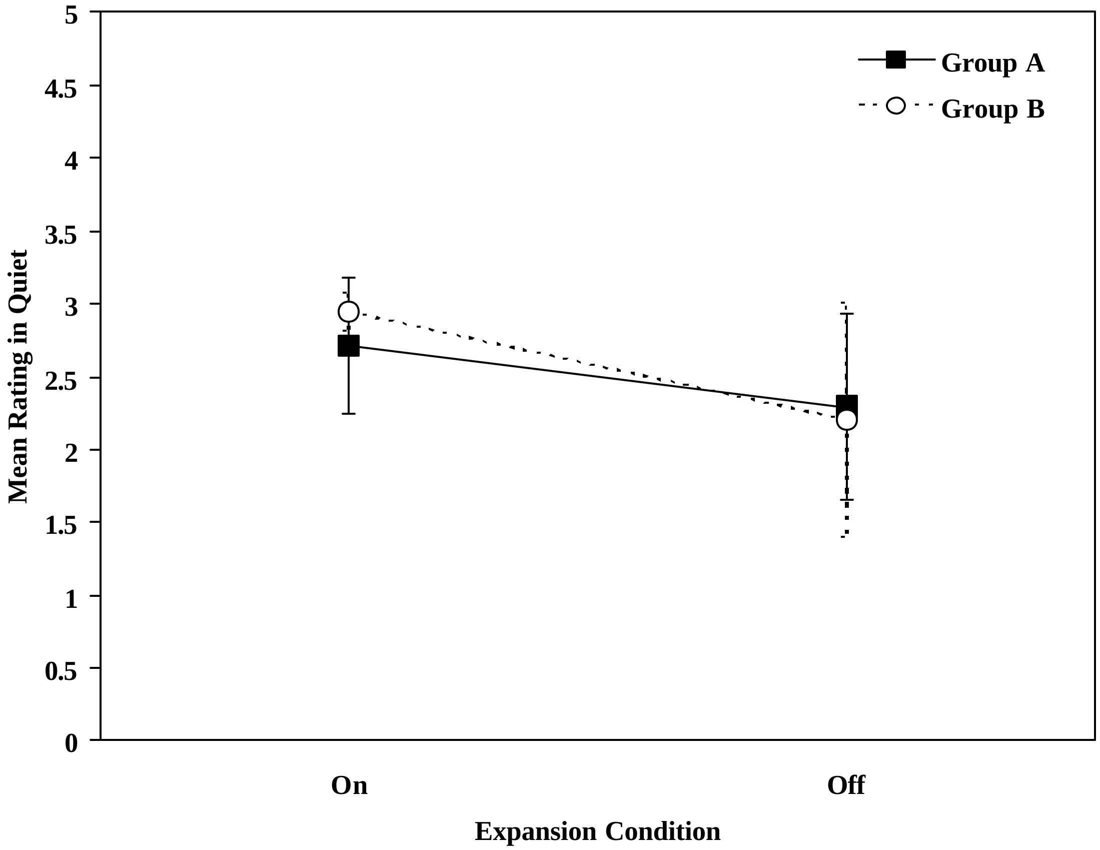


Figure 8. Average mean rating in quiet for Experiment I

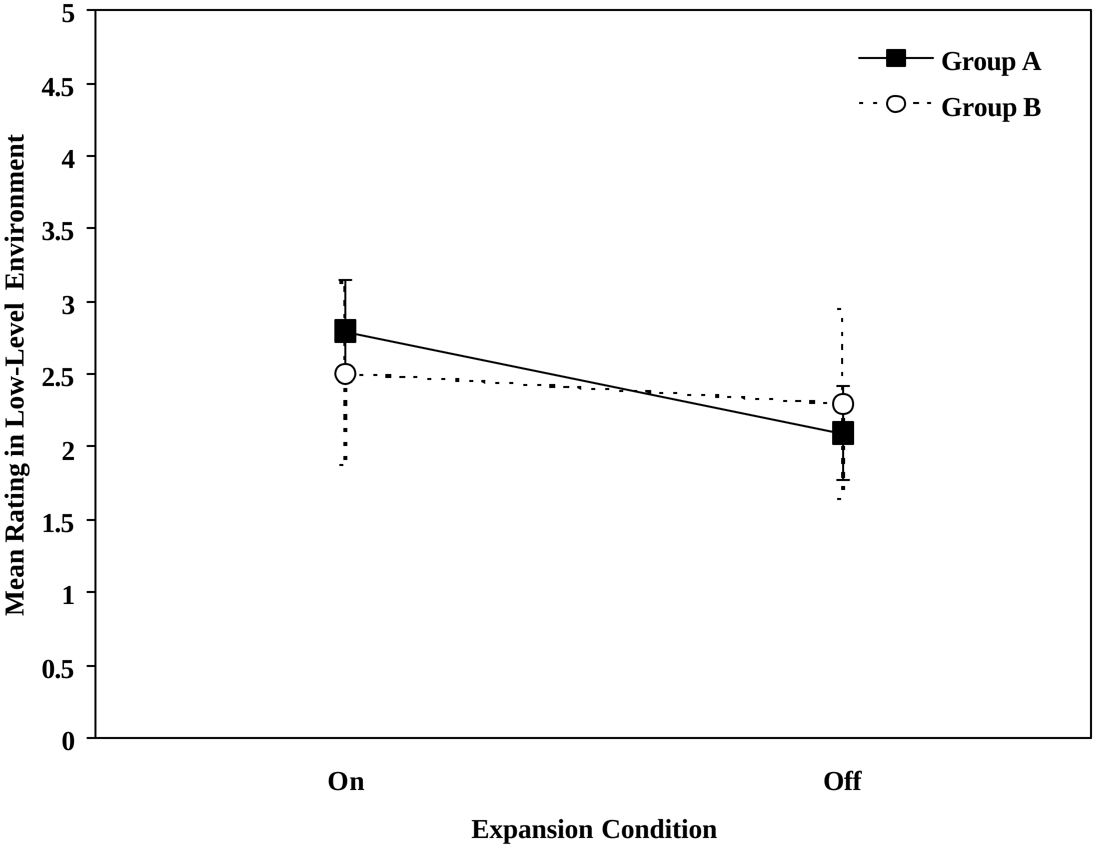


Figure 9. Average mean rating in low-level environments for Experiment I

Preference

The third purpose of Experiment I was to determine if the expansion feature affected listener preference. Following the completion of the ten-day trial period, each subject was asked to determine which expansion condition they preferred when listening in quiet and when listening in everyday low-level environments. Preference results are displayed in Figure 10. Ideally, a loglinear model with three factors (environment, group, and expansion preference) would have been conducted to analyze the preference data. However, each cell would not contain the minimum required observations (5) to conduct such analyses. Therefore, a one-sample chi-square test was conducted to assess whether listeners preferred the expansion on condition, the expansion off condition, or did not have a preference when listening in a quiet environment. The results of the test were significant, $\chi^2(2, N = 20) = 19.9$, $p<.05$. The proportion of listeners that preferred the expansion on condition ($\underline{P} = .8$) was greater than the hypothesized proportion of .33, while the proportion of listeners that preferred the expansion off condition ($\underline{P} = .05$) and the proportion that did not have a preference ($\underline{P} = .15$) were less than the hypothesized proportion of .33. Follow-up testing indicated that the proportion of listeners preferring the expansion on condition differed significantly from the proportion of listeners preferring the expansion off condition, $\chi^2(1, N = 17) = 13.23$, $p<.05$, and the proportion of listeners not having a preference, $\chi^2(1, N = 19) = 8.89$, $p<.05$. Follow-up testing further indicated, however, that the proportion of listeners preferring the expansion off condition did not differ significantly from the proportion of listeners that did not have a preference, $\chi^2(1, N = 4) = 1.80$, $p>.05$. These results suggest that listeners preferred the expansion on condition when listening in a quiet environment.

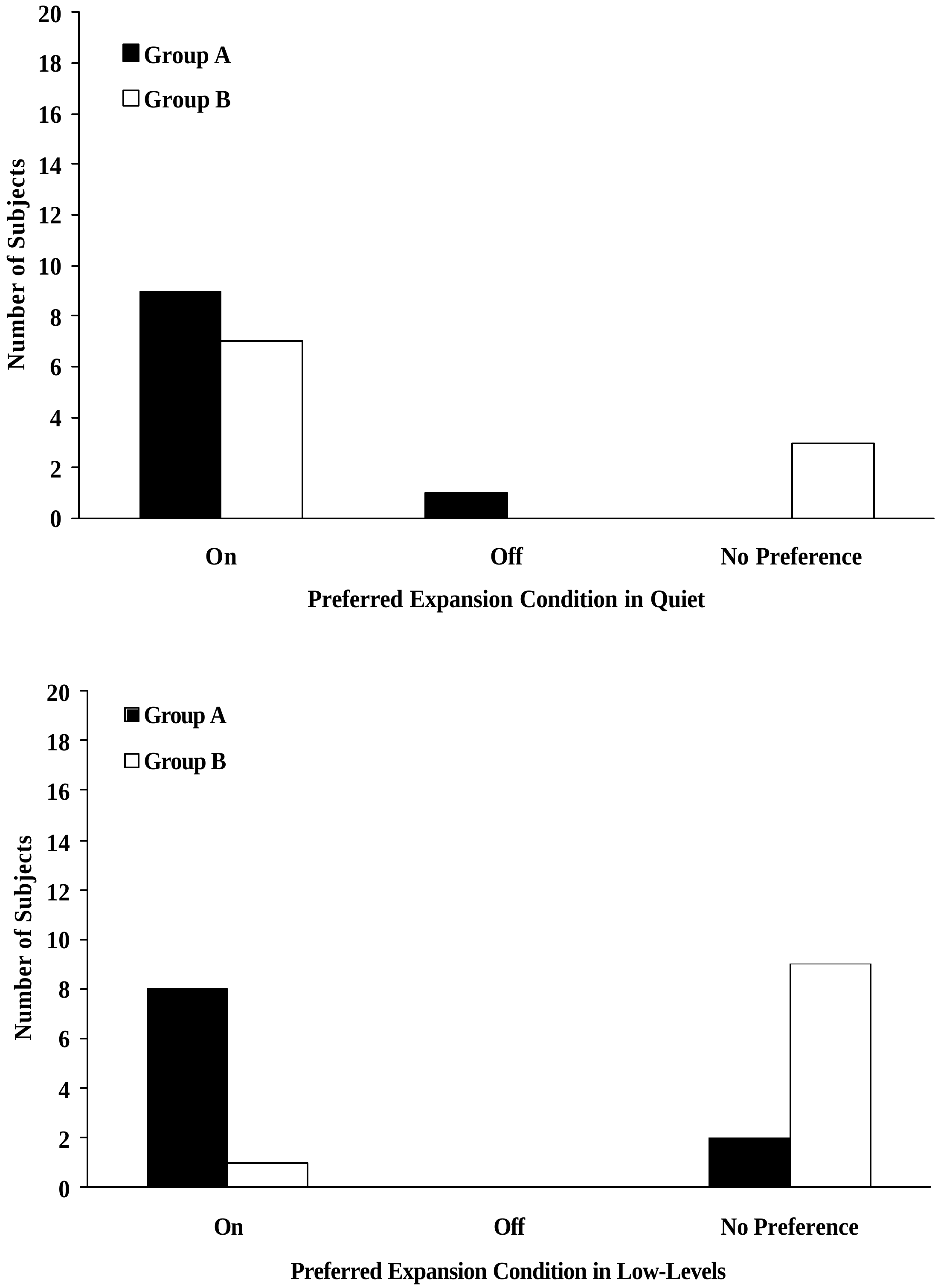


Figure 10. Average mean preference data for Experiment I.

A one-sample chi-square test was also conducted to assess whether listeners preferred the expansion on condition, the expansion off condition, or did not have a preference when listening in an everyday low-level environment. The results of the test were not significant, $\chi^2(1, N = 20) = 0.2$, $p>.05$. These results suggest that listeners do not have a preferred expansion condition when listening in an everyday low-level environment.

Further examination of the data suggested that expansion preference in a low-level environment may be related to hearing sensitivity. For example, 8 out of 10 subjects with better hearing sensitivity (Group A) preferred the expansion on condition while 2 subjects had no preference. Conversely, 1 out of 10 participants with poorer hearing sensitivity (Group B) preferred the expansion on condition while 9 participants had no preference. Therefore, a two-way contingency table analysis was conducted to determine if expansion preference in a low-level environment was related to hearing sensitivity. The two variables were hearing sensitivity with two levels (Group A and Group B) and expansion preference with two levels (on or no preference). Results indicated that hearing sensitivity and expansion preference were significantly related, Pearson $\chi^2(1, N = 20) = 9.89$, $p<.05$. These results suggested that listeners with better hearing sensitivity were more likely to prefer the expansion on condition when listening in a low-level environment than listeners with poorer hearing sensitivity.

Experiment II: Time Constants

Objective Evaluation

The first purpose of Experiment II was to objectively evaluate listener performance in quiet and in noise for each expansion time constant. The Connected Speech Test (CST) was conducted at 65 dB SPL for each participant to assess performance in quiet. CST scores were then averaged across the twenty subjects for each expansion time constant (table 3, Figure 11).

A two-way analysis of variance was performed to evaluate the effects of expansion time constant and hearing sensitivity on performance in quiet. The dependant variable was CST score. The within-subject factor was expansion time constant with four levels (128 ms, 512 ms, 2094 ms, and 4096 ms). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effects for expansion time constant [F(3,54) = 13.989, p<.05] and for group [F(1,18) = 5.083, p<.05]. The expansion time constant by group interaction was not significant [F(3,54) = 2.097, p>.05]. Pairwise comparisons (Bonferroni) conducted to investigate the expansion time constant main effect indicated significant performance differences between all time constants tested with two exceptions. Significant performance differences were not evident between the 128 ms and 512 ms conditions or the 2094 ms and 4096 ms conditions. These results indicated that performance in quiet decreased as the expansion time constant increased for each group. The Hearing in Noise Test (HINT) was conducted at 65 dB SPL for each participant to assess performance in noise. HINT scores were then averaged across the twenty participants for each expansion time constant (table 4, Figure 12). A two-way analysis of variance was performed to evaluate the effects of expansion time constant and hearing sensitivity on performance in noise. The dependant variable was HINT score. The within-subject factor was expansion time constant with four levels (128 ms, 512 ms, 2094 ms, and 4096 ms). The between-subject factor was group with two levels (Group A and Group B). The analysis revealed significant main effects for expansion time constant [F(3,54) = 13.962, p<.05] and for group [F(1,18) = 11.458, p<.05]. The expansion time constant by group interaction was not significant [F(3,54) = 2.623, p>.05]. Pairwise comparisons (Bonferroni) conducted to investigate the expansion time constant main effect indicated significant performance differences between all time constants tested. These results indicated that performance in noise decreased as the expansion time constant increased for each group.

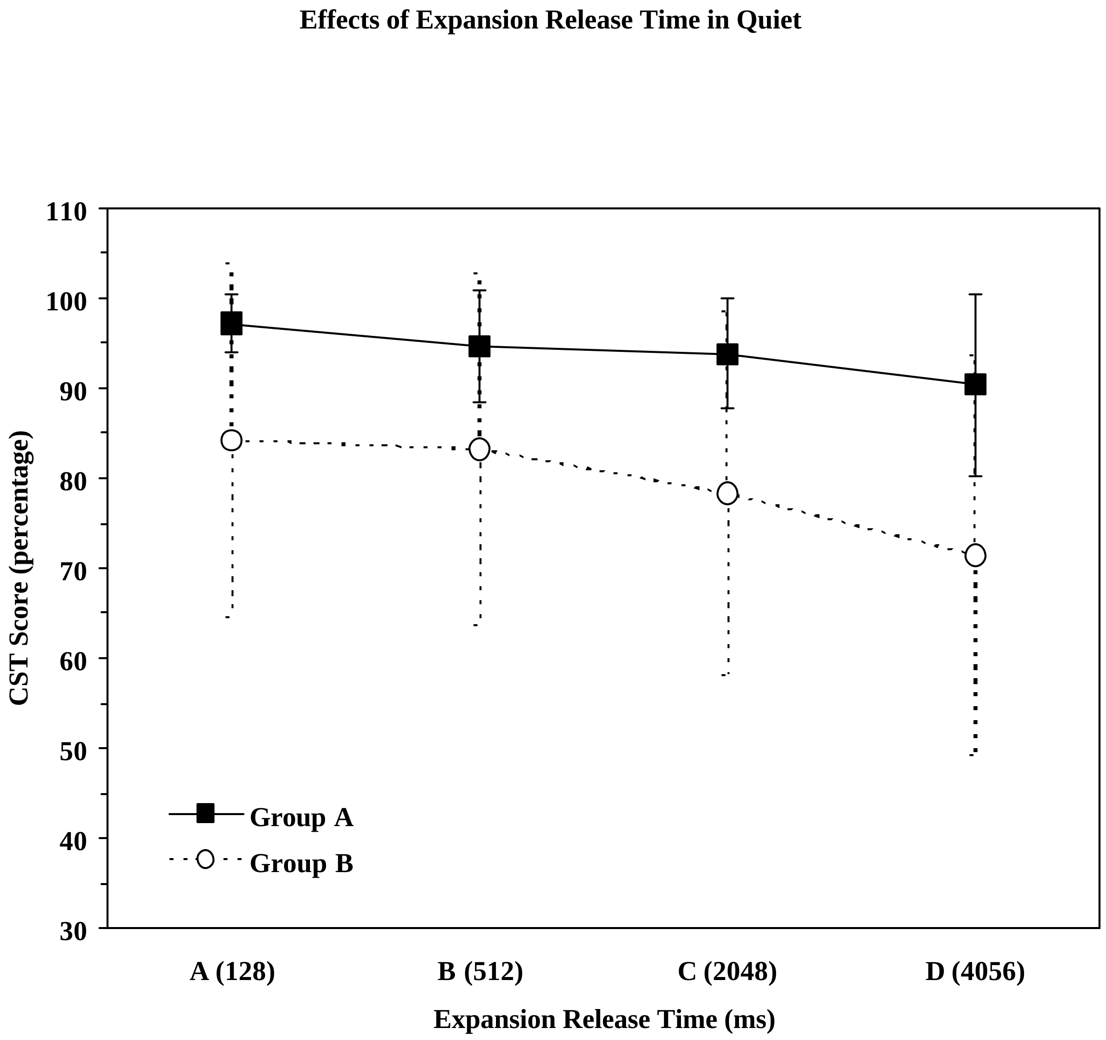


Figure 11. Average CST scores for Experiment II

Table 4. Hearing in Noise Test means and standard deviations for Experiment II.

Group	Expansion Time Constant (ms)	Mean	Standard Deviation
A	128	0.9	2.1
	512	2	2.5
	2048	2.5	3.4
	4056	3	3.6
B	128	4.1	2
	512	4.9	1.8
	2048	6.5	2.2
	4056	7.6	2.1

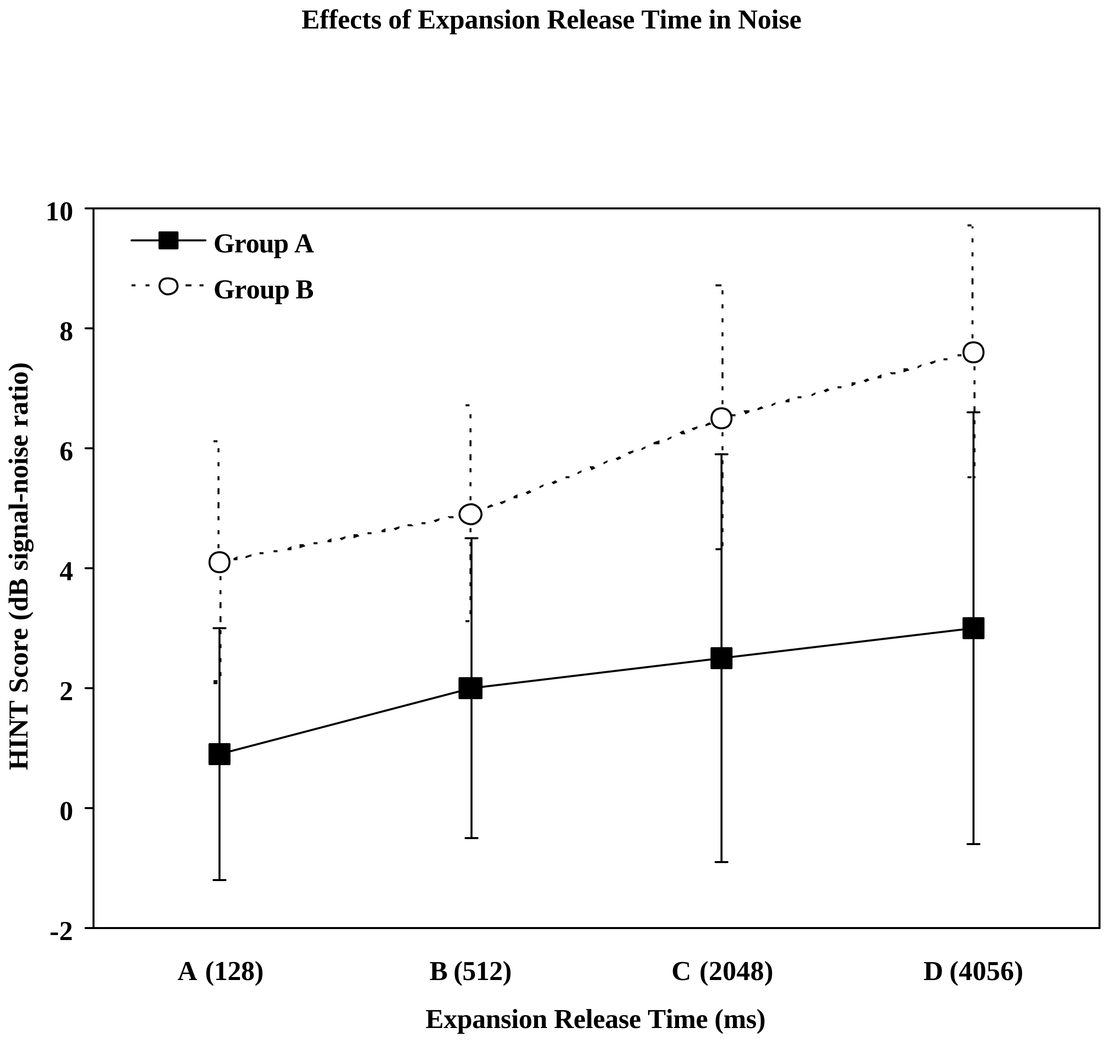


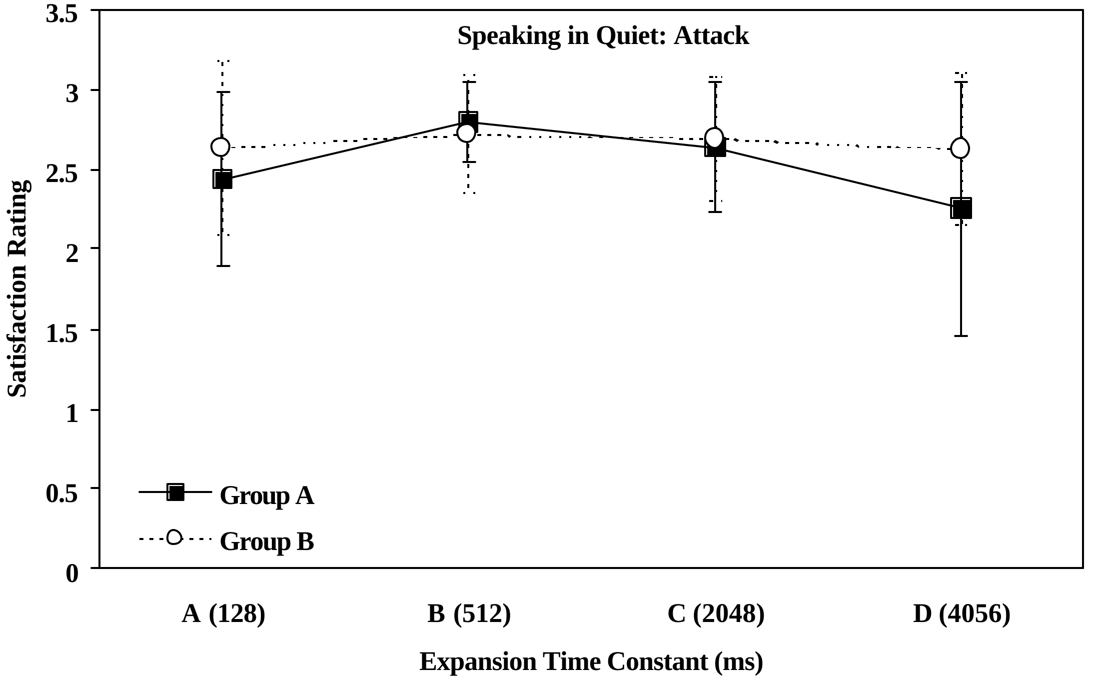
Figure 12. Average HINT scores for Experiment II

Subjective Evaluation

The second purpose of Experiment II was to obtain subjective evaluations of hearing instrument performance in quiet and in noise for each expansion condition. Each participant utilized both hearing instruments for a ten-day trial period and completed a daily subjective evaluation of each expansion time constant (Appendix B). For each expansion time constant, participants were asked to rate their satisfaction regarding the speed of background noise reduction when speaking and listening in quiet and in everyday low-level environments.

From the data collection phase, it was obvious that some individuals felt certain expansion time constants reduced background noise too quickly (rating = 1 or 2) whereas other listeners felt certain expansion time constants reduced background noise too slowly (rating = 5 or 4). Both of these instances were viewed as ratings of dissatisfaction with the speed of noise reduction provided by the expansion time constant. In order to evaluate the expansion feature in terms of satisfaction versus dissatisfaction, individual satisfaction ratings of 4 or 5 were recoded to ratings of 2 or 1 respectively to simply reflect dissatisfaction with the expansion time constant. Individual satisfaction ratings were then averaged across the ten days for each expansion time constant when speaking (Figures 13 & 14) and listening (Figures 15 & 16) in quiet and in low-level environments.

Four two-way analyses of variance were performed to evaluate the effects of expansion time constant and hearing sensitivity on satisfaction ratings in quiet and in low-level environments when speaking. The dependant variable was mean satisfaction rating. The within-subject factor was expansion time constant with four levels (128 ms, 512 ms, 2094 ms, and 4096 ms). The between-subject factor was group with two levels (Group A and Group B). The analyses revealed no significant main effects for expansion time constant, group, or for the



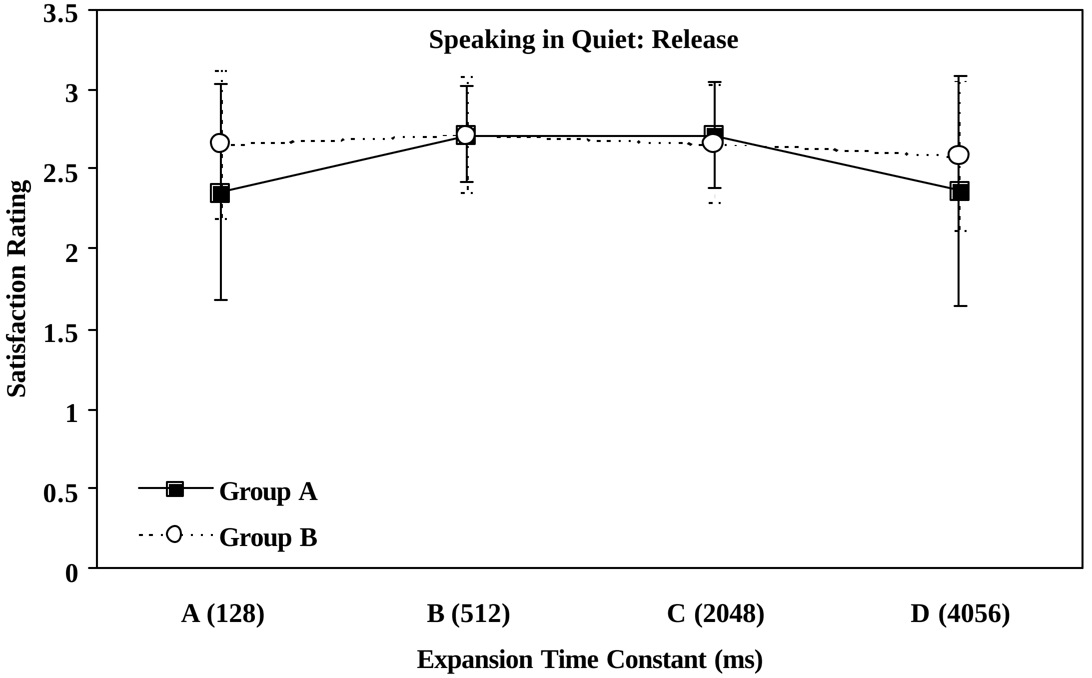


Figure 13. Average mean ratings for speaking in quiet environments

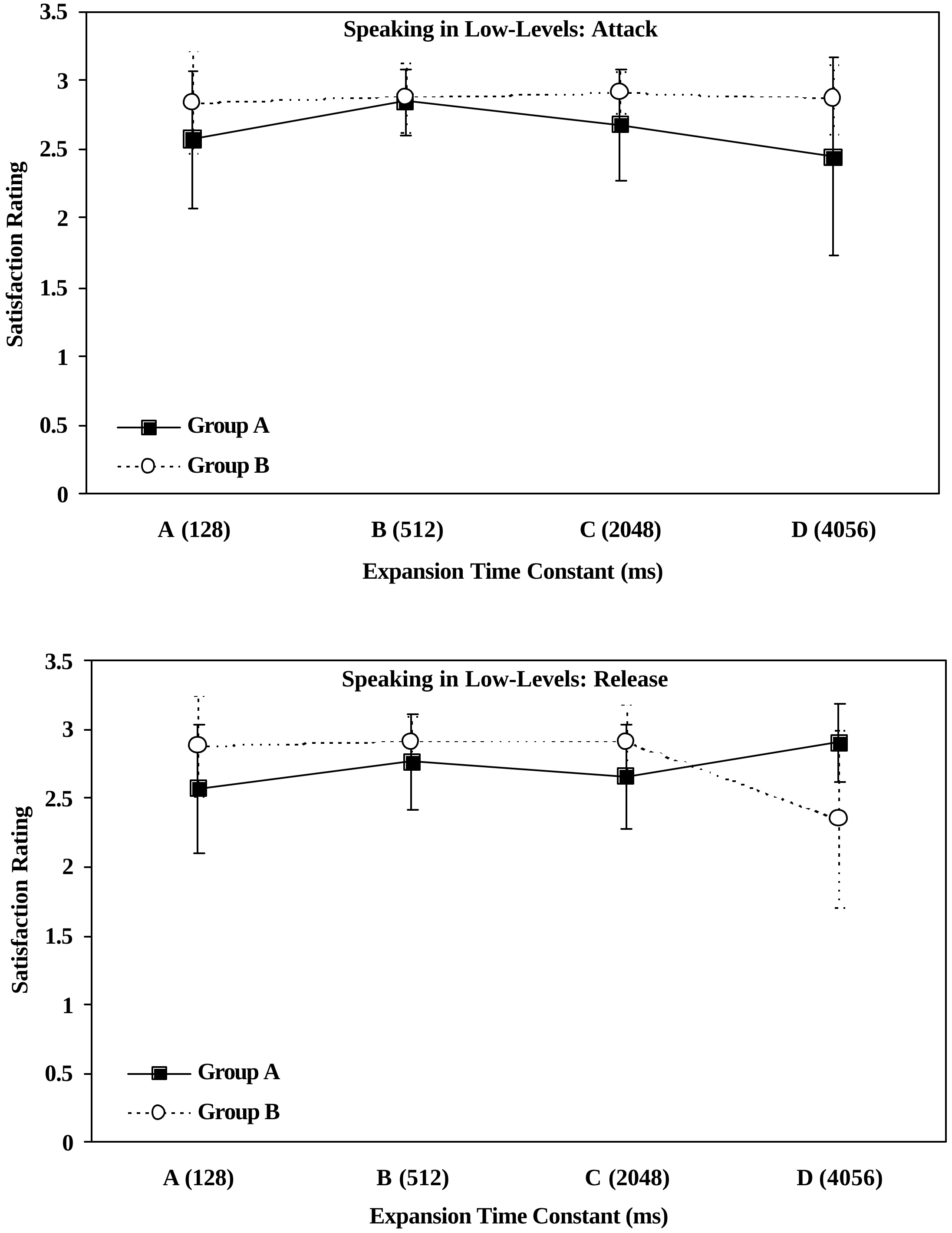
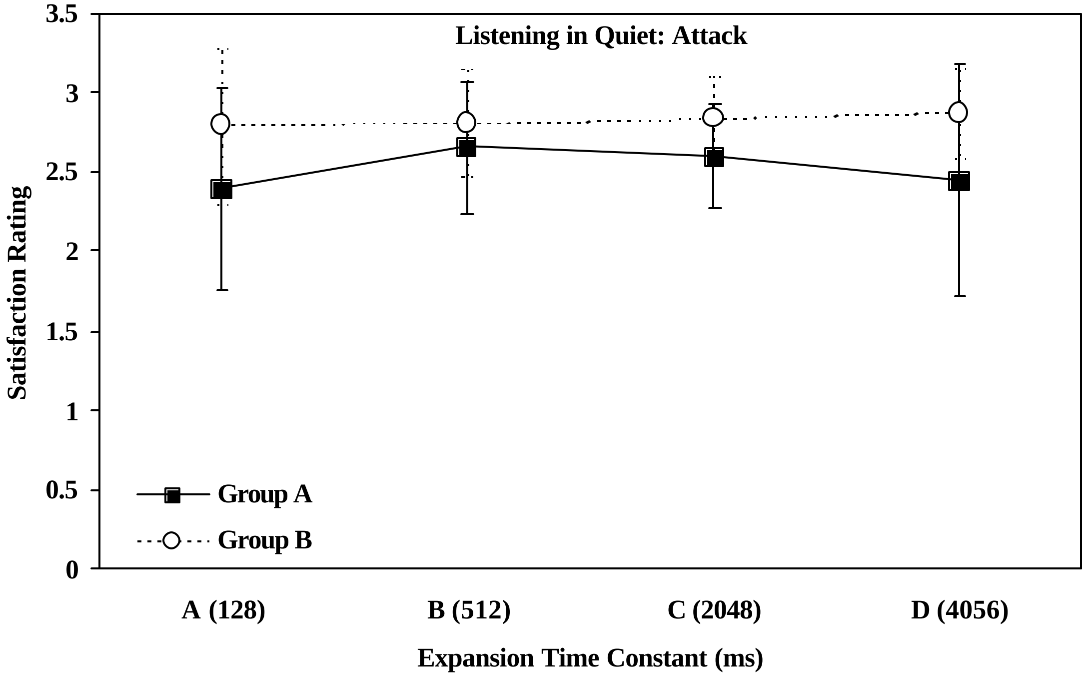


Figure 14. Average mean ratings for speaking in low-level environments



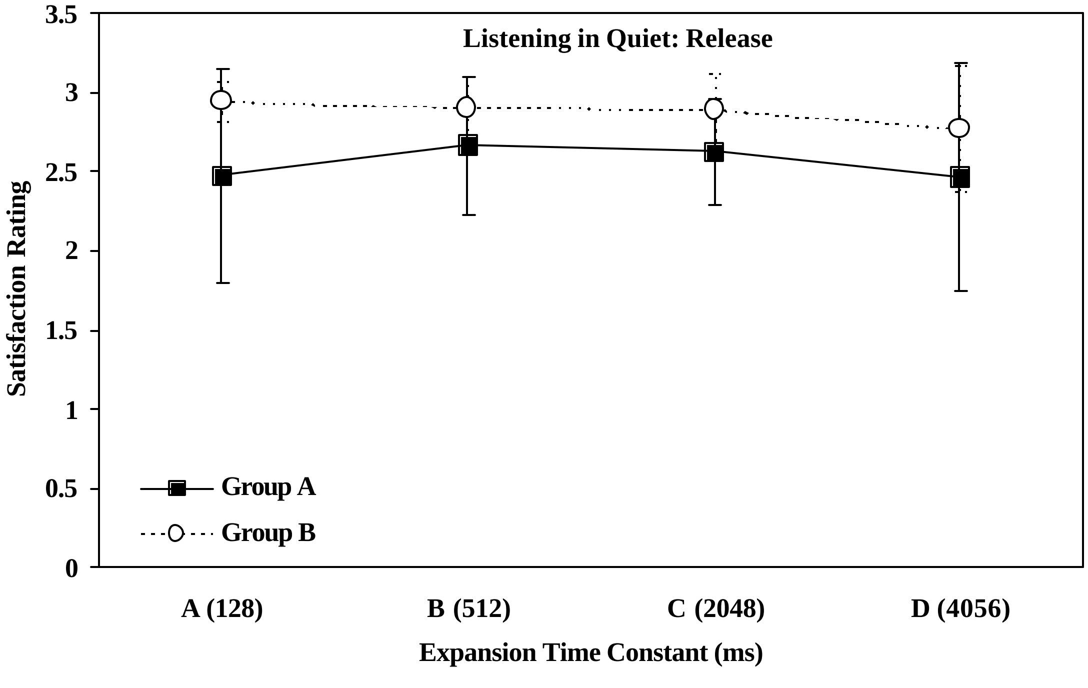
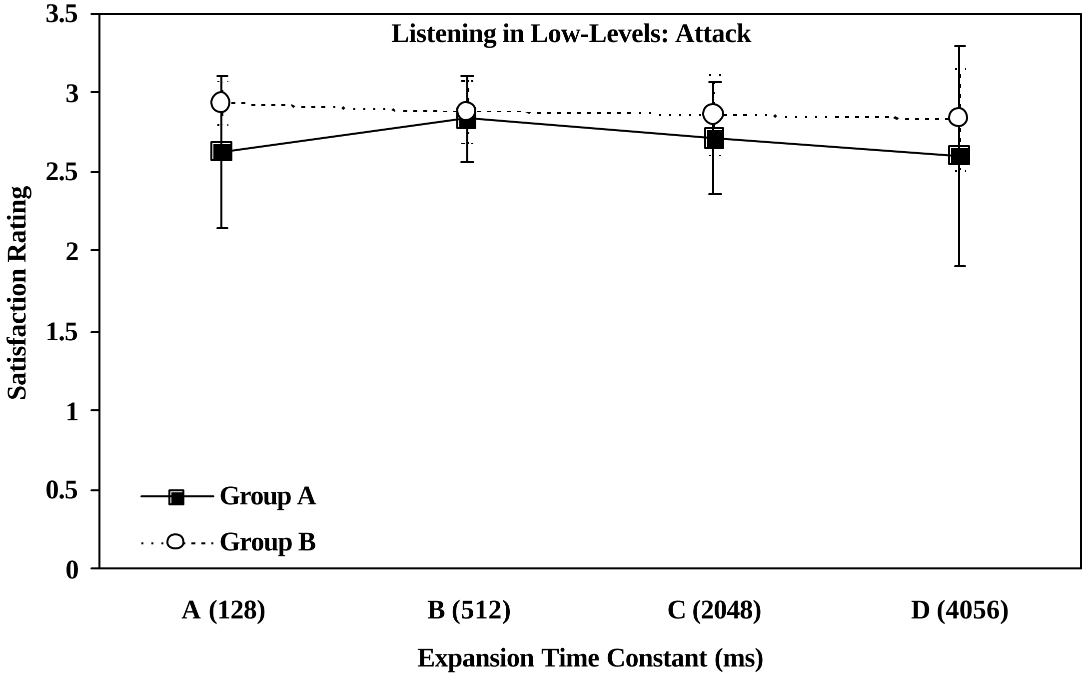


Figure 15. Average mean ratings for listening in quiet environments



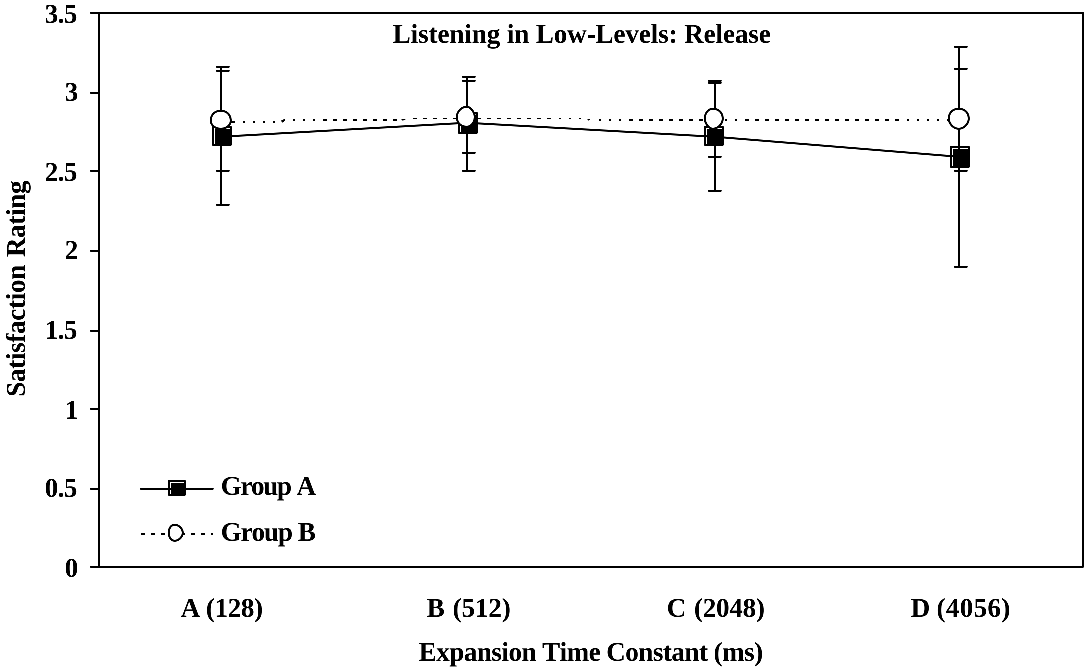


Figure 16. Average mean ratings for listening in low-level environments

expansion time constant by group interaction with one exception (table 4). A significant expansion time constant by group interaction was evident when evaluating the release time in low-level environments [F(3,54) = 8.09, p<.05]. These results indicated that varying the expansion time constant did not significantly affect satisfaction ratings when speaking for participants in each group.

Four two-way analyses of variance were also performed to evaluate the effects of expansion time constant and hearing sensitivity on satisfaction ratings in quiet and in low-level environments when listening. The dependant variable was mean satisfaction rating. The within-subject factor was expansion time constant with four levels (128 ms, 512 ms, 2094 ms, and 4096 ms). The between-subject factor was group with two levels (Group A and Group B). The analyses revealed no significant main effects for expansion time constant, group, or for the expansion time constant by group interaction with one exception (table 5). A significant group effect was evident when evaluating the release time [F(1,18) = 6.925, p<.05] in a quiet environment. In general, these results indicated that varying the expansion time constant did not significantly affect satisfaction ratings when listening for subjects in each group.

Preference

The third purpose of Experiment II was to determine if the expansion time constant affected listener preference. Following the completion of the ten-day trial period, each participant was asked to determine which expansion time constant they preferred when listening and speaking in quiet and when in everyday low-level environments. Preference results are displayed in Figures 17 & 18.

Ideally, a loglinear model with three factors (environment, group, and expansion time constant preference) would have been conducted to analyze the preference data. However, each cell would not contain the minimum required observations (5) to conduct such analyses.

Table 5: ANOVA results for satisfaction ratings in Experiment II.

Speaking					
	Quiet: Attack		F Value	df	Significance
		Time Constant	2.568	3,54	0.64
		Group	0.730	1,18	0.40
		Time Constant x Group	1.244	3,54	0.30
	Quiet: Release		F Value	df	Significance
		Time Constant	1.905	3,54	0.14
		Group	0.613	1,18	0.44
		Time Constant x Group	0.902	3,54	0.44
	Low-Level: Attack		F Value	df	Significance
		Time Constant	0.199	3,54	0.66
		Group	3.534	1,18	0.07
		Time Constant x Group	0.452	3,54	0.51
	Low-Level: Release		F Value	df	Significance
		Time Constant	1.629	3,54	0.19
		Group	0.107	1,18	0.74
		Time Constant x Group	8.09	3,54	0.00
Listening					
	Quiet: Attack		F Value	df	Significance
		Time Constant	0.542	3,54	0.65
		Group	4.422	1,18	0.06
		Time Constant x Group	0.576	3,54	0.63
	Quiet: Release		F Value	df	Significance
		Time Constant	0.655	3,54	0.58
		Group	6.925	1,18	0.01
		Time Constant x Group	0.052	3,54	0.78
	Low-Level: Attack		F Value	df	Significance
		Time Constant	0.864	3,54	0.46
		Group	2.004	1,18	0.17
		Time Constant x Group	0.856	3,54	0.47
	Low-Level: Release		F Value	df	Significance
		Time Constant	0.441	3,54	0.72
		Group	0.930	1,18	0.34
		Time Constant x Group	0.315	3,54	0.81

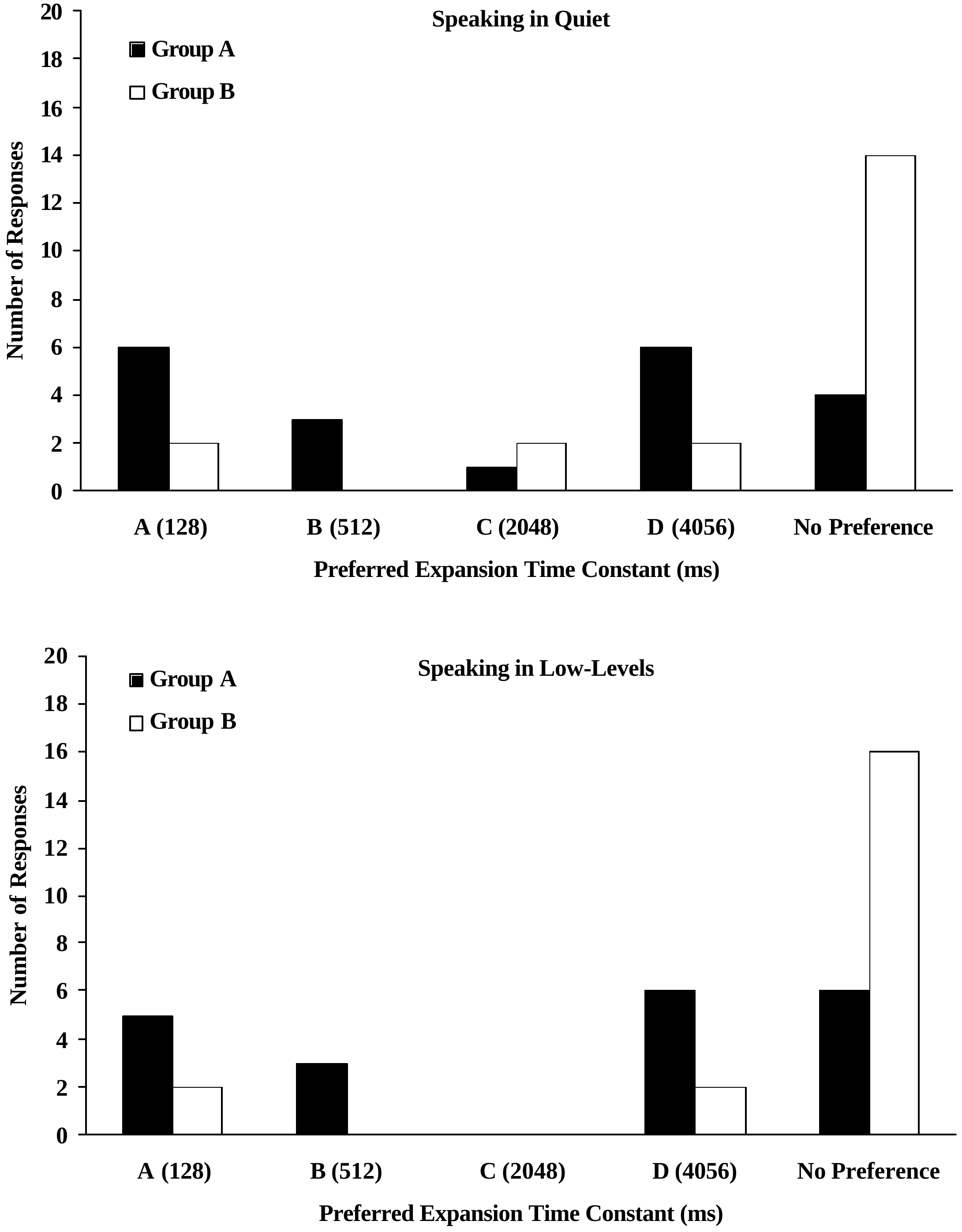


Figure 17. Average mean preference data when speaking

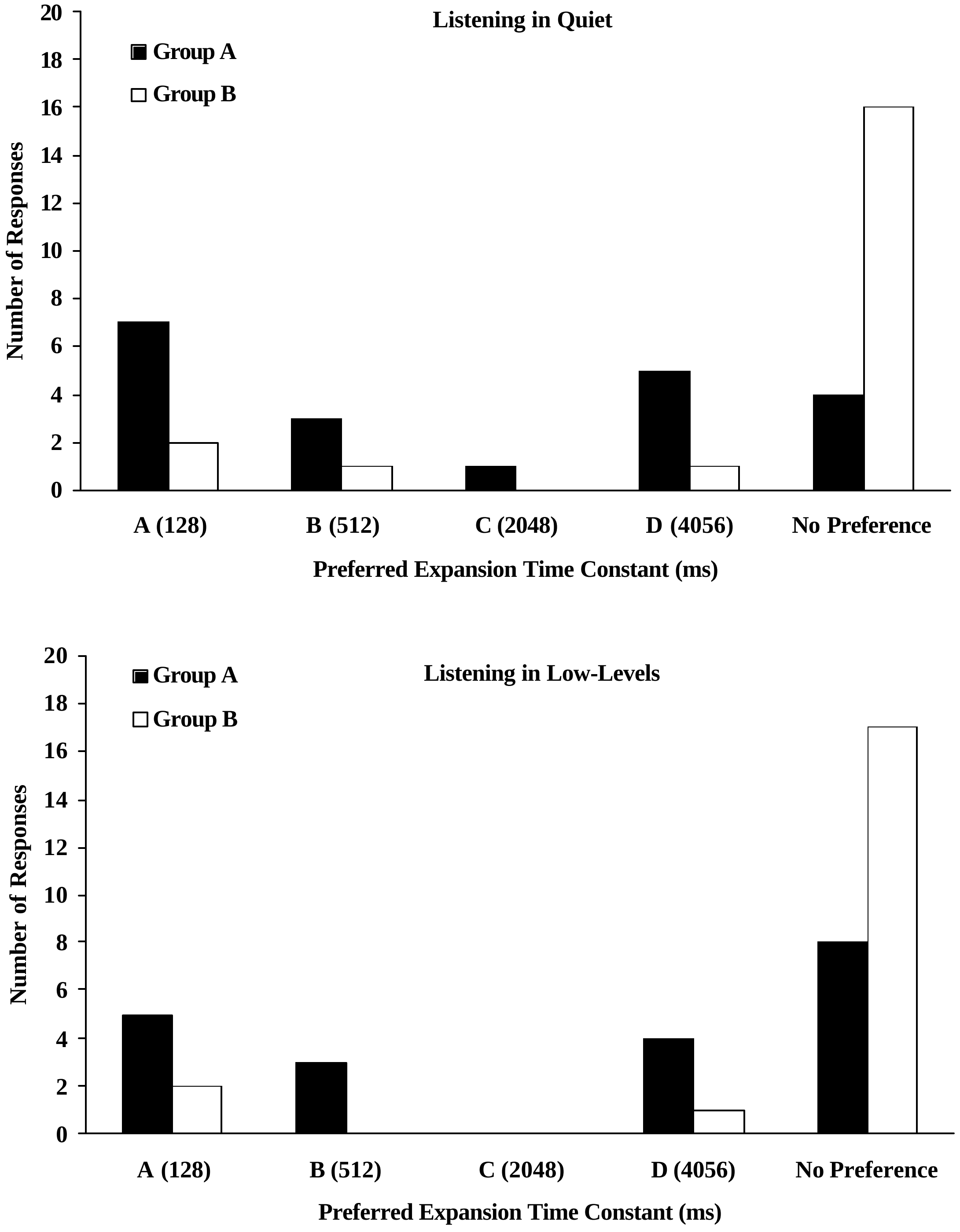


Figure 18. Average mean preference data when speaking

Therefore, a one-sample chi-square test was conducted to determine if listeners had a preferred expansion time constant when speaking in a quiet environment. The results of the test were significant, $\chi^2(4, N = 40) = 18.7, p<.05$. The proportion of listeners that did not have a preferred time constant (P = .45) was greater than the hypothesized proportion of .2, while the proportion of listeners that preferred the 128 ms time constant (P = .2), the 512 ms time constant (P = .07), the 2094 ms time constant (P = .07), the 4096 ms time constant (P = .2) were less than or equal to the hypothesized proportion of .2. A follow-up test was conducted for subjects that indicated a preferred time constant when speaking in quiet. The results of the test were not significant, $\chi^2(3, N = 22) = 4.5, p>.05$. These results suggested that listeners did not have a preferred expansion time constant when speaking in a quiet environment.

A one-sample chi-square test was also conducted to determine if listeners had a preferred expansion time constant when speaking in a low-level environment. The results of the test were significant, $\chi^2(3, N = 40) = 20.6, p<.05$. The proportion of listeners that did not have a preferred time constant (P = .55) was greater than the hypothesized proportion of .2, while the proportion of listeners that preferred the 128 ms time constant (P = .17), the 512 ms time constant (P = .07), the 2094 ms time constant (P = .00), and the 4096 ms time constant (P = .2) were less than or equal to the hypothesized proportion of .2. A follow-up test was conducted for subjects that indicated a preferred time constant when speaking in a low-level environment. The results of the test were not significant, $\chi^2(2, N = 18) = 2.3, p>.05$. These results suggested that listeners did not have a preferred expansion time constant when speaking in a low-level environment.

A one-sample chi-square test was conducted to determine if listeners had a preferred expansion time constant when listening in a quiet environment. The results of the test were significant, $\chi^2(4, N = 40) = 26.7, p<.05$. The proportion of listeners that did not have a preferred time constant ($\underline{P} = .5$) was greater than the hypothesized proportion of .2, while the proportion of listeners that preferred the 128 ms time constant ($\underline{P} = .2$), the 512 ms time constant ($\underline{P} = .1$), the 2094 ms time constant ($\underline{P} = .02$), the 4096 ms time constant ($\underline{P} = .15$) were less than or equal to the hypothesized proportion of .2. A follow-up test was conducted for subjects that indicated a preferred time constant when listening in quiet. The results of the test were not significant, $\chi^2(3, N = 20) = 6.8, p>.05$. These results suggested that listeners did not have a preferred expansion time constant when listening in a quiet environment.

Lastly, a one-sample chi-square test was also conducted to determine if listeners had a preferred expansion time constant when listening in a low-level environment. The results of the test were significant, $\chi^2(3, N = 40) = 30.8, p<.05$. The proportion of listeners that did not have a preferred time constant ($\underline{P} = .62$) was greater than the hypothesized proportion of .2, while the proportion of listeners that preferred the 128 ms time constant ($\underline{P} = .17$), the 512 ms time constant ($\underline{P} = .07$), the 2094 ms time constant ($\underline{P} = .00$), and the 4096 ms time constant ($\underline{P} = .12$) were less than or equal to the hypothesized proportion of .2. A follow-up test was conducted for participants that indicated a preferred time constant when speaking in a low-level environment. The results of the test were not significant, $\chi^2(2, N = 15) = 1.6, p>.05$. These results suggested that listeners did not have a preferred expansion time constant when listening in a low-level environment.

CHAPTER V

DISCUSSION

Experiment I: Expansion On vs. Expansion Off

Probe Microphone Measures

Probe microphone measures were obtained with the loudspeaker deactivated to verify appropriate functioning of the expansion feature. Results indicated that the expansion feature significantly reduced in-stiu levels when in a quiet setting (Figure 2). These results were in agreement with Ghent et al. (2000) and demonstrated that expansion technology does result in reduced gain of low-level input signals. Probe microphone measures were also obtained at the input levels used in Experiment I to determine the response characteristics of the hearing instruments in each expansion condition. Results indicated that the mean responses with expansion were not significantly different from the mean responses without expansion when input signals were at or above the kneepoint of expansion; however, the mean responses of the input signal below the kneepoint did significantly differ (Figures 3-5). These results suggest that expansion may be affective at reducing the gain of input signal levels below the expansion kneepoint; however, the effectiveness of expansion may be reduced when listeners are in environments with speech or ambient noise levels equal to or greater than the kneepoint of expansion.

Results of probe microphone testing further suggested that selection of the expansion kneepoint may play an important role in determining the effectiveness of the feature for a given listener. For example, the expansion kneepoint utilized in this study was 50 dB SPL; however, some listeners may rarely encounter listening situations outside the clinical setting where input signals are below the kneepoint of expansion whereas other listeners may frequently encounter listening situations outside the clinical setting where input signals are below the kneepoint of expansion. Consequently, the expansion feature may become engaged more frequently for some listeners than for other listeners, thereby resulting in variable benefit to the end users.

Objective Evaluation

The first purpose of Experiment I was to objectively evaluate listener performance in quiet and in noise for each expansion condition. Results of testing in quiet and in noise indicated that performance improved as intensity level increased and that listeners with less hearing-impairment performed significantly better than listeners with more severe hearing-impairment. Significant main effects for group and for level were expected due to the fact that normal hearing listeners perform better on speech recognition tasks than hearing impaired listeners and tat performance improves as presentation level increases for each group (Davis and Silverman, 1960).

Results further indicated that listeners in both groups performed significantly better in quiet and in noise when the expansion feature was deactivated and that activation of the expansion feature significantly reduced listener's performance in quiet and in noise when the input signal level was at or below the kneepoint of expansion. Results obtained with the 40 dB SPL stimuli presentation were expected given the fact that expansion reduces the amplification of input signals below the kneepoint of expansion. In fact, examination of Figure 3 revealed significantly reduced in-situ output levels for the expansion on condition when the input signal (40 dB SPL) was below the expansion kneepoint (50 dB SPL). Consequently, the degraded ability to recognize speech stimuli presented below the expansion kneepoint during the expansion on condition may have been due to the reduced audibility of speech cues necessary for accurate feature identification.

Similar reasoning may be used to explain the speech recognition deficits observed in the expansion on condition for stimuli presented at the kneepoint of expansion. Examination of Figure 4 revealed similar in-situ output levels for each expansion condition when the input signal (50 dB SPL) equaled the expansion kneepoint (50 dB SPL). These results were expected since the stimulus amplitude did not fall below the expansion kneepoint at any frequency during the measurement. As a result, the expansion feature should not have been engaged when obtaining the probe microphone measurement at 50 dB SPL; therefore, output spectra would be expected to be similar for each expansion condition. However, the amplitude of speech fluctuates over time as much as 30 dB. Consequently, amplitude variations in the temporal waveform could have resulted in activation of the expansion feature, thereby reducing the amplification of low-level speech cues necessary for accurate feature identification.

Another purpose of the present study was to determine if performance with expansion was related to degree of hearing loss. Listeners with more severe hearing loss require greater gain than listeners with less severe hearing loss. However, expansion technology reduces the gain provided to signals below the expansion kneepoint by an amount defined by the expansion ratio. The hearing instruments in the present study utilized an expansion ratio of 1:2. As a result, input signals below the expansion kneepoint received a 50% gain reduction during the expansion on condition. Consequently, a listener with a severe hearing loss that received 40 dB of gain in the expansion off condition would receive 20 dB of gain during the expansion on condition while a listener with a mild hearing loss that received 12 dB of gain in the expansion off condition would receive 6 dB of gain during the expansion on condition. Therefore, listeners with greater hearing loss should receive a larger gain reduction than listeners with less hearing loss. Although results of the present study indicated that expansion degraded speech recognition ability in quiet and in noise for listeners in both groups, the magnitude of the speech recognition deficits produced by the expansion feature were comparable for all listeners. Therefore, results of the present study suggested that expansion technology significantly reduced speech recognition ability of all listeners in quiet and in noise when the input signal level was at or below the kneepoint of expansion. Furthermore, performance with expansion was not related to degree of hearing loss.

Subjective Evaluation

The second purpose of Experiment I was to obtain subjective evaluations of hearing instrument performance in quiet and in noise for each expansion condition. In quiet, results indicated that listeners in each group were more satisfied with the amount of noise reduction when expansion was activated for both quiet and low-level environments. Results further suggested that listeners with less hearing-impairment indicated a larger satisfaction increase when using expansion in low-level environments than listeners with more severe hearing-impairment.

Each participant was also asked to indicate which expansion condition they preferred when listening in quiet and when listening in everyday low-level environments to determine if the expansion feature affected overall listener preference. Results suggested that listeners preferred the expansion on condition when listening in a quiet environment. Results further suggested, however, that listeners with better hearing sensitivity were more likely to prefer the expansion on condition than listeners with poorer hearing sensitivity when listening in a low-level environment. The expansion preference was likely due to the fact that the WDRC hearing instrument was less noisy. Meaning the expansion feature is significantly reducing the internal noise created by the microphone and the components of the circuitry, making the hearing instrument much quieter.

Conclusions & Clinical Implications

The data from Experiment I revealed that expansion significantly affected hearing instrument users performance and preference. When signals were below the designated expansion kneepoint and expansion was activated, participants, in both groups, performed significantly poorer. However, participants in both groups preferred the expansion condition. Dispensers should be aware that the use of expansion may reduce the audibility of internal noise generated by the hearing instrument; however, the ability to understand low-level speech will be compromised as well. It may be recommended to have persons use one memory with expansion and one without or develop an expansion switch, in which the hearing instrument user could activate the expansion feature when understanding was not necessary.

Altering the kneepoint and time constants may also impact results with expansion. Kneepoint is related to frequency of expansion engagement. Lowering the kneepoint, meaning softer signals would activate the expansion feature, would be expected to result in low frequency of engagement providing less subjective benefit, but better intelligibility scores. Higher kneepoints, meaning louder sounds would receive a gain reduction, would be expected to result in high frequency of engagement providing more subjective benefit, but poorer intelligibility scores. Future research should investigate the effects of expansion kneepoint on benefit with the feature to determine the most appropriate settings. Time constants, another factor that could impact results with expansion, are examined in the next phase of the study.

Experiment II: Time Constants

Objective Evaluation

The first purpose of Experiment II was to objectively evaluate listener performance in quiet and in noise for each expansion time constant. Results of testing in quiet and in noise indicated that performance decreased as the expansion time constant increased and that listeners with less hearing-impairment performed significantly better than listeners with more severe hearing-impairment.

The significant main effect for group was expected to the fact that normal hearing listeners perform better on speech recognition tasks than hearing impaired listeners. Listeners, in both groups, scored poorer with longer time constants, because expansion was taking a longer period of time to release, and appropriate gain was not being allocated to the speech signal. For example, if an individual is sitting in a library and their hearing instrument is in the expansion condition, a fast expansion time constant would allow for their hearing instrument to quickly and appropriately give the input signal the amount of gain needed to hear the signal, where as if it were a long expansion time constant their hearing instrument would not give the input signal the correct amount of gain fast enough and some of the signal may be missed. Therefore, the decreased speech recognition ability may be attributed to increasing the release time of expansion.

Subjective Evaluation

The second purpose of Experiment II was to obtain subjective evaluations of performance in quiet and in low-level noise for each expansion condition. Each participant was asked to rate their satisfaction with the rate of background noise reduction for each of the expansion time constants while listening and speaking in quiet and in low-everyday environments. Results revealed that the only significant subjective performance difference evident was the evaluation of the release time while listening in a quiet environment. These results suggest that participants could only distinguish differences in the amount of time between a quiet moment and the appropriate amount of gain required to hear the intended signal. Therefore, given that no single time constant was deemed superior nor objectionable, hearing instrument manufactures and audiologists have the option to choose an appropriate expansion time constant based on objective measures rather than subjective ones.

Each participant was also asked to determine which expansion time constant they preferred when listening and speaking in quiet and in everyday low-level environments. Results revealed no significant preference in any of the conditions.

Conclusions & Clinical Implications

The data from Experiment II revealed that expansion time constants affect hearing instrument user performance, but not preference. If performance decreases with increases in time constant duration, but there is no preference between short and long time constants, a shorter time constant should be implemented. Data from the objective portion of Experiment II suggested that there was very little difference between the 128 ms and the 512 ms conditions. Previous research examining time constants, in traditional compression, determined that a "middle ground" time constant should be implemented (Sandlin, 2000); so it could be hypothesized that the 512 ms condition would be the best choice, for optimum performance and preference. Future research should investigate the efficacy of using variable attack and release times of expansion.

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APPENDIX A: EXPERIMENT I RATING FORM

Quiet Listening Environment	Rate your satisfaction with the amount of background noise reduction (**1=**much too little, **2=**too little**,** **3=**ok, **4=**too much, **5=**much too much**)** **Circle your favorite setting**		General Listening Environment	Rate your satisfaction with the amount of background noise reduction (**1=**much too little, **2=**too little, **3=**ok, **4=**too much, **5=**much too much) **Circle your favorite setting**
Evaluation Session 1:	Memory 1:_____ Memory 2:_____ **COMMENTS:**			Memory 1:_____ Memory 2:_____ **COMMENTS:**
Evaluation Session 2:	Memory 1:_____ Memory 2:_____ **COMMENTS:**			Memory 1:_____ Memory 2:_____ **COMMENTS:**

APPENDIX B: EXPERIMENT II RATING FORMS

Quiet Listening Environment	**“Speaking➔ Quiet”** Rate your satisfaction with the speed of background noise reduction (**1=**much too fast, **2=**too fast**,** **3=**ok, **4=**too slow, **5=**much too slow**)** **Circle your favorite setting**	**“Quiet➔ Speaking”** Rate your satisfaction with the speed of background noise/speech gain increase (**1=**much too fast, **2=**too fast, **3=**ok, **4=**too slow, **5=**much too slow) **Circle your favorite setting**	**General Listening Environment**	**“Speaking➔ Quiet”** Rate your satisfaction with the speed of background noise reduction (**1=**much too fast, **2=**too fast, **3=**ok, **4=**too slow, **5=**much too slow) **Circle your favorite setting**	**“Quiet➔ Speaking”** Rate your satisfaction with the speed of background noise/speech gain increase (**1=**much too fast, **2=**too fast, **3=**ok, **4=**too slow, **5=**much too slow) **Circle your favorite setting**
Evaluation Session 1:	Memory 1:_____ Memory 2:_____ Memory 3:_____ **Memory 4:**_____ **COMMENTS:**	Memory 1:_____ Memory 2:_____ Memory 3:_____ **Memory 4:**_____ **COMMENTS:**		Memory 1:_____ Memory 2:_____ Memory 3:_____ **Memory 4:**_____ **COMMENTS:**	Memory 1:_____ Memory 2:_____ Memory 3:_____ **Memory 4:**_____ **COMMENTS:**

Quiet Listening Environment	**“Listening→ Quiet”** Rate your satisfaction with the speed of background noise reduction (**1=**much too fast, **2=**too fast**,** **3=**ok, **4=**too slow, **5=**much too slow**)** **Circle your favorite setting**	**“Quiet→ Listening”** Rate your satisfaction with the speed of background noise/speech gain increase (**1=**much too fast, **2=**too fast, **3=**ok, **4=**too slow, **5=**much too slow) **Circle your favorite setting**	**General Listening Environment**	**“Listening→ Quiet”** Rate your satisfaction with the speed of background noise reduction (**1=**much too fast, **2=**too fast, **3=**ok, **4=**too slow, **5=**much too slow) **Circle your favorite setting**	**“Quiet→ Listening”** Rate your satisfaction with the speed of background noise/speech gain increase (**1=**much too fast, **2=**too fast, **3=**ok, **4=**too slow, **5=**much too slow) **Circle your favorite setting**
Evaluation Session 1:	Memory 1:_____ Memory 2:_____ Memory 3:_____ **Memory 4:**_____ **COMMENTS:**	Memory 1:_____ Memory 2:_____ Memory 3:_____ **Memory 4:**_____ **COMMENTS:**		Memory 1:_____ Memory 2:_____ Memory 3:_____ **Memory 4:**_____ **COMMENTS:**	Memory 1:_____ Memory 2:_____ Memory 3:_____ **Memory 4:**_____ **COMMENTS:**

VITA

Ms. Ashley B. Hill was born in Orlando, Florida, on April 6, 1980. She grew up and went to high school in Tazewell, Virginia, a small rural farming community in the Applachain Mountains. She received her bachelor of arts in communications disorders from Louisiana State University- Baton Rouge in May 2002. Upon completion of her undergraduate studies, Ms. Hill entered the audiology graduate program in the Department of Communication Sciences and Disorders at Louisiana State University- Baton Rouge. Future plans include completion of the degree of the Master of Arts and beginning her clinical fellowship year in Baton Rouge.