THE EFFECT OF LISTENER GROUP AND MASKER CONDITION ON AUDITORY MEMORY SCORES

by

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Introduction

Pure-Tone Audiometry

According to Gatlin and Dhar (2021), for almost a century, the “gold standard” for hearing measurement has been the pure-tone threshold test. The patient’s pure-tone thresholds indicate the softest sound audible to the patient at least 50% of the time at each test frequency. Standard test frequencies include 250, 500, 1000, 2000, 3000, 4000, 6000, and 8000 Hz. Thresholds are expressed in terms of decibels hearing level (dB HL) and frequency (Hz). Baiduc et al. (2013) wrote that pure-tone stimuli are delivered via insert earphones, supra-aural headphones, or a bone conduction vibrator on the mastoid process. Bone conduction testing can be administered to determine the type of hearing loss whether it be sensorineural (involving the inner ear mechanisms), conductive (involving outer and middle ear mechanisms), or mixed (affecting both). According to ASHA (2005), pure-tone thresholds are used for monitoring or diagnostic reasons. A monitoring threshold assessment is designed as a part of hearing loss prevention programs or medical management for ototoxic medication. A diagnostic threshold assessment determines the presence and degree of hearing loss at the standard frequencies and may be used to determine fitness for duty. The air and/or bone conduction thresholds are used to determine the presence and degree of hearing loss (ASHA, 2005). A mild hearing loss is identified as a pure-tone threshold average (for 500, 1000, and 2000 Hz) between 26-40 dB HL, moderate between 41-55 dB HL, moderately severe between 56-70 dB HL, severe between 71-90 dB HL, and profound ≥ 91 dB HL (Baiduc et al., 2013).

The interpretation of the audiogram has implications in every application of audiology. In industry or military settings, an audiogram acts as a legal document which illustrates any changes in hearing status that could impact workers' compensation or veterans' benefits (Gatlin & Dhar, 2021). According to Campo et al. (2009), factors that have ototoxic effects that could alter hearing include medications such as antibiotics and diuretics or chemicals such as p-Xylene and n-Hexane, which are common in refinery, the paint industry, aviation, military, and fire service. In combination with noise exposure, the inhalation of smoke, fumes, powders, dust, and vapors from solvents or thinners could induce hearing dysfunction. Exposure to chemical substances can also impair the cochlea, vestibulo-cochlear apparatus, the auditory nerve, or central nervous system. Frequent, persistent noise exposure can result in mechanical damage which presents as broken, collapsed, or floppy cilia of the cochlear hair cells or tears in Reissner's or the reticular membrane.

According to Tufts et al. (2009), pure-tone thresholds are necessary for the evaluation of auditory fitness for duty (AFFD). AFFD refers to sufficient hearing abilities for safe and effective job performance and is important in occupations which involve the safety of others or are typically hazardous, such as operating vehicles or aircrafts, mining, military, law enforcement, etc. (Tufts et al., 2009). Gatlin and Dhar (2021) noted that in the clinic, AFFD is critical for educating the patient, forming treatment recommendations for hearing loss, and fitting hearing aids. Finally, in research, an audiogram may determine the inclusion/exclusion of participants.

Speech-in-Noise Testing

The World Health Organization (WHO) reports that normal hearing is indicated by a threshold average at 500, 1000, 2000, 4000 Hz with a pure-tone average (PTA) less than or equal to 20 dB HL for the better ear (Mathers et al., 2000). WHO (2021) uses this pure-tone average to infer speech recognition in noise ability. The question arises, what is the relationship between PTA and speech recognition in noise ability. Dickson et al. (1946) administered three tests: one sentence test, one word test, and one sound articulation test. They were given to 100 aircrew personnel. The authors reported that scores varied just as widely between subjects with normal audiograms as those with hearing loss. These results support the idea that the audiogram cannot predict the ability to recognize speech-in-noise. Because speech-in-noise ability may be independent of an individual's pure-tone thresholds, it is necessary to have speech-in-noise assessments designed to represent hearing ability in everyday environments. The AzBio Test (Spahr et al., 2012) or the Hearing in Noise Test (HINT; Nilsson et al., 1994; Vermiglio, 2008) were developed using stimuli that mimic common listening environments to evaluate speech perception. The AzBio Test is made up of sentence lists with similar levels of difficulty. The test consists of 15 lists of 20 sentences read by two female and two male talkers. During the list equivalency study, the materials were presented at a fixed SNR of +5 dB SNR or +10 dB SNR to avoid ceiling effects. Each sentence is scored by the number of words repeated correctly; the percent correct score is calculated and recorded per list. The HINT, which comprises 25 phonemically balanced lists of ten sentences, is administered with adaptive testing procedures in order to measure speech reception thresholds (SRTs; Nilsson et al., 1994). Results are reported as a signal-to-noise (SNR) ratio in dB. For example, in a 72 dB noise, the speech reception threshold was 69.08, reported as a SNR of -2.92 (Nilsson et al., 1994).

These tests address the ecological validity needed in assessments, which is "a measure of how test performance predicts behaviors in real-world settings" (Barker et al., 2014). The purpose of these tests is to provide an understanding of a patient's hearing in everyday listening conditions and communication situations (Keidser et al., 2020). By design, these tests require interaction such as repetition of phrases and comprehension which furthers their ecological validity (Keidser et al., 2020). This information goes beyond the information provided by pure-tone and speech recognition thresholds.

Working Memory

Adequate working memory is required for many complex cognitive abilities. The term "working" refers to the mental effort necessary to store and manipulate information held in the mind (Marrone et al., 2015). According to Goldstein (2010), information can only be stored with working memory for about 10-15 seconds. Auditory working memory is the ability to retain auditory stimuli in the mind after termination of stimuli and perform mental operations on them (Kaiser, 2015). According to Baddeley et al. (2003), it is an attentionally limited control system which involves temporary storage and manipulation of information. This temporary storage system is essential to support our capacity for thinking and language processing. Daily tasks requiring auditory working memory include remembering a phone number while dialing or retaining auditory input before taking notes. Brown (1958) indicated the decay of temporary short-term memory can occur within seconds if rehearsal is prevented.

According to Marrone et al. (2015), the auditory environment plays a role in working memory performance; there is an increased perceptual demand as competing auditory input increases. With focused attention, individuals may perform well on simple tasks in quiet acoustic environments such as writing down a grocery list while a partner is listing items to the writer. When the perceptual demands of the task are increased, such as writing down the list with competing conversations interfering with the target information, the same individuals may show a decline in performance. In terms of perceptual processing, working-memory capacity as seen in the reading span task have shown moderate to strong positive correlation with several speech perception-in-noise tests (Parbery-Clark et al., 2011). The question is then: which masking conditions seem to increase perceptual demands the most in a focused working memory task?

Working Memory Assessment

The Digit Span, which is a part of the Wechsler Adult Intelligence Scale (WAIS-III) and Wechsler Memory Scale (WMS-III), requires subjects to repeat a series of digits that increase in length during the test (Cullum, 1998). Subjects make an oral response during the test (Powell and Hiatt, 1996). Two modalities, which are subtests of the Wechsler Adult Intelligence Scale, include Digit Spans Forward and Backward. According to Cullum (1998), the Digit Span Forward measures simple attention/memory, and the Digit Span Backwards represents a task that relies more on working memory skills than forward. Powell and Hiatt (1996) sought to understand the differences between auditory and visual recall on Forward and Backwards Digit Spans by testing 80 subjects. Their results suggest that in a clinical setting, the mode of presentation (auditory vs. visual) influences the Backwards Digit Span only. Results showed that the visual administration of an individual number of strings at 1 second intervals resulted in the recall of one digit more than when presented auditorily for Backward Digit Span. No significant modality effects were found for Forward Digit Span.

Lad et al. (2020) tested 44 participants with no neurological or psychiatric history with audiometric thresholds between -5.8-14.2 dB HL using the SiN (Speech-in-Noise perception) and forward and backward digit span measures of phonological working memory. They tested two auditory WM precision metrics: frequency and amplitude modulation and found that better

SiN ability (lower thresholds for reporting sentences in multi-talker babble) is significantly correlated with higher frequency working memory precision.

Jagadeesh and Kumar (2019) investigated the effects of linguistic content of a masker on working memory. The Backward Digit Span was administered to 24 normal hearing individuals in two and eight speaker babble, forward and reversed at +5 dB SNR. The results showed that the lexical-semantic information in the forward maskers produced the greatest deterioration in working memory scores. In the two-speaker babble conditions, there was a statistically significant main effect for masker type when forward and reverse conditions were compared ($p<0.001$). The maskers containing the greatest amounts of semantic information negatively impacted working memory by interfering with the perception of the target speech. The mismatch between the target and internal phonological representation taxes working memory. However, with a favorable SNR, stress on the working memory system is minor.

Semantic Interference

Carhart et al. (1969) used the term "semantic interference" to refer to the deterioration of task performance in the presence of semantic information of maskers. This could also be referred to as perceptual masking, and in this event, performance of a task requiring listening can be compromised due to incoming signals which are highly similar, i.e., when the target is speech and the masker contains speech. Semantic interference was also reported by Janssen et al. (2008) in both immediate and delayed naming conditions.

Self-Reported Speech Perception in Noise Difficulty

A common complaint among adults is difficulties perceiving speech in noise. King (1954) published an article describing "psychogenic deafness," a term used to convey the loss of the capacity for discriminative listening. This arises from the voluntary or involuntary exclusion of sound by the patient. The effects of psychogenic deafness depend on the amount of attention and concentration on certain sounds. Middelweerd et al. (1990) described the difference in speech recognition in noise ability between two groups with and without self-reported speech recognition in noise with normal pure-tone thresholds. The group with speech-in-noise complaints had poorer speech perception in noise thresholds than the control group. The term King-Kopetzky Syndrome (KKS) was coined by Hinchcliffe (1992) to indicate self-reported speech perception in noise difficulty in the presence of normal pure-tone thresholds. There is a lack of studies revealing the effect of self-perceived difficulty with speech recognition in noise on auditory working memory performance.

Research Questions and Hypotheses

For the purpose of linking speech perception and auditory memory, the Auditory Digit Span was selected with no visual feedback. The present study seeks to answer the following questions based on the literature review: 1) What is the effect of a self-reported listener group (KKS vs. control) on auditory memory scores? 2) What is the effect of semantic interference on auditory memory scores?

The hypotheses were as follows:

H1. The KKS group will perform poorer than the control group on auditory memory tasks in the presence of noise.

H2. The semantic content of the maskers will have a negative effect on auditory memory performance.

Methods

Participants

Forty-five native English speakers participated in this study. All participants were between the ages of 21-29 (mean age=21) and had normal pure-tone thresholds (≤ 25 dB HL, 0.25 – 8.0 kHz) except for two subjects who had thresholds of 30 dB HL at 8.0 kHz. Fifteen participants reported "having trouble remembering things"; six of which reported difficulty with speech-in-noise perception.

Questionnaire

All participants completed a detailed Qualtrics™ survey which included items on daily experiences with memory and perceived speech-in-noise difficulty (Qualtrics, Provo, UT). Participants were asked "Do you have difficulty hearing speech in a noisy environment, such as a crowded restaurant?" Participants who reported no difficulty were assigned to the control group. Participants who reported difficulty were assigned to the KKS group (Hinchcliffe, 1992).

The Digit Span Test

In a pilot study, the Digit Span Test was used in reverse recall to evaluate auditory working memory (Wechsler, 1955). The test was administered in four-talker forward, four-talker backwards, conversational masker forward, and conversational masker backwards conditions. Due to the presence of floor effects in preliminary testing, the Digit Span Reverse Recall was replaced with forward recall, which examines simple memory/attention. This study followed the revised administration and scoring of the Digit Span published by Blackburn & Benton (1957). Participants' Digit Span scores were recorded as the number of correctly repeated strings before three consecutive failed repetitions. The strings began with two digits and increased by one digit every two strings. The digits and maskers were presented binaurally at 65 dBA (0 dB SNR). The test stimuli were delivered under supra-aural headphones in a sound-treated booth. All Digit Span lists and masker conditions were randomized.

The masker types chosen for this study include semantically meaningful and anomalous maskers to accomplish the goal of revealing "semantic interference" on memory. The semantically meaningful maskers used in this study included four-talker forward and conversational forward. The four-talker forward condition was taken from the same Auditec source file as used for the Quick Speech-in-Noise Test (Killion et al., 2004). The conversational masker was found on youtube.com from Everyday Cinematic Sounds (free high-quality sound effects). The four-talker and conversational maskers had the same RMS level as the original AzBio masker. These conditions were chosen to provide linguistic distraction from the target speech. Anomalous maskers included four-talker backwards and conversational backwards. These maskers were from the same sources as above but were time reversed to be stripped of all morphological content that could distract from the target stimuli.

Statistical Analysis

JMP Pro 14 was used for analyses. Repeated measures ANOVAs were used to evaluate the main effects of group (KKS vs. control) and masker condition (four-talker forward and backwards and conversational forward and backwards). The post hoc testing was conducted using one sample t-tests to evaluate differences in performances between masking conditions.

Results

Descriptive Statistics

The descriptive statistics are presented in Table 1 for the four masker conditions. Overall, the participants performed best in conversational masker conditions. The mean score for backwards conditions is greater than forward conditions. All conditions had a range of six strings except for conversational masker forward (range=9).

Digit Span Score Condition	Mean	SD	Min	Max	Range
Four-Talker Forward	2.03	2.02	0	6	6
Four-Talker Backwards	3.33	1.71	0	6	6
Conversational Masker Forward	4.02	2.10	1	10	9
Conversational Masker Backwards	4.75	1.57	2	8	6

Table 1. Descriptive Statistics for Digit Span Scores.

Group

To address the first hypothesis, a repeated measures ANOVA was conducted and revealed no statistically significant main effect for listening group ($F=0.07$, $p=0.796$). Figure 1 shows mean Digit Span scores per group per condition. Although there are no statistically significant differences between the groups, it is interesting to note that the KKS group scores are slightly better in the forward conditions and the control group scores are slightly better in the backwards conditions.

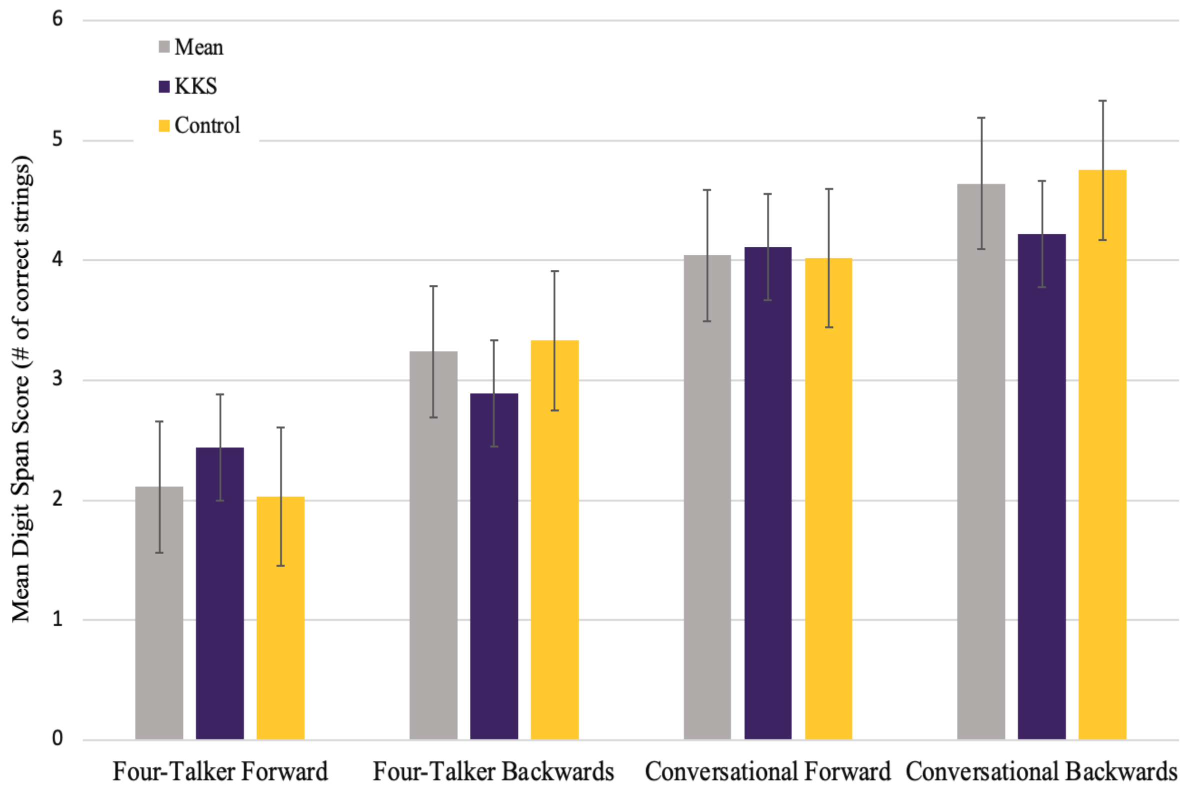

Figure 1. Mean Digit Span scores per listening group by listening condition. Overall mean Digit Span scores (both groups) are indicated in gray, KKS mean Digit Span scores are indicated in purple, and control group mean Digit Span scores are indicated in gold.

Listening Condition

To address the second hypothesis, a repeated measures ANOVA revealed a statistically significant main effect for listening condition (F=8.00, *p*=0.0003). A post hoc analysis using one sample t-tests revealed statistically significant differences (*p*≤0.0254) between all condition comparisons (see Table 2). The analysis also revealed evidence of semantic interference on memory scores. The scores for the four-talker backwards condition were statistically significantly better than the four-talker forward condition (mean difference = 1.13, *p*<0.0001) and the scores for the conversational masker backwards were statistically better than the conversational masker forward condition (mean difference = 0.6, p=0.0254). Additionally, results from the post hoc analysis using one sample t-tests revealed statistically significant differences between conversational and four-talker masker score. The greatest difference was found for conversational masker backwards – four-talker forward score (mean difference=2.53, p<.0001). The smallest difference was found for conversational masker forward – four-talker backwards score (mean difference=0.8, p=0.0155).

Digit Span Condition Score Difference	Mean difference	*p*-value
Conversational Masker Forward - Four Talker Forward score	1.93	***p*<.0001**
Conversational Masker Forward – Four-Talker Backwards score	0.8	***p*=0.0155**
Conversational Masker Backwards - Conversational Masker Forward	0.6	***p*=0.0254**
Conversational Masker Backwards – Four-Talker Forward score	2.53	***p*<.0001**
Conversational Masker Backwards – Four-Talker Backwards score	1.4	***p*<.0001**
Four-Talker Backwards – Four-Talker Forward score	1.13	***p*<.0001**
Four-Talker Forward score – Four-Talker Backwards score	0.8	***p*=0.0155**

Table 2. Mean differences between all listening conditions.

Figure 2 illustrates the semantic interference and semantic advantage of the four-talker and conversational maskers. Forward scores were subtracted from backwards to measure semantic content. Semantic interference was indicated by differences between backwards and forward greater than 0. Semantic advantage was indicated by differences less than or equal to 0. On the y-axis, the Digit Span four-talker forward score is subtracted from the Digit Span four-talker backwards score. Positive values indicate semantic interference for Digit Span four-talker masker on the y-axis. The figure shows that 60% of the participants showed evidence of semantic interference in the four-talker masker conditions. Semantic advantage for four talker maskers was found for 40% of the participants. On the x-axis, the Digit Span conversational masker forward score is subtracted from the Digit Span conversational masker backwards score. Positive values indicate semantic interference for Digit Span conversational masker on the x-axis. In conversational masker conditions, 51% of participants showed evidence of semantic interference. Semantic advantage for conversational maskers was found for 49% of the participants. Greater semantic interference reflects greater semantic content in the condition.

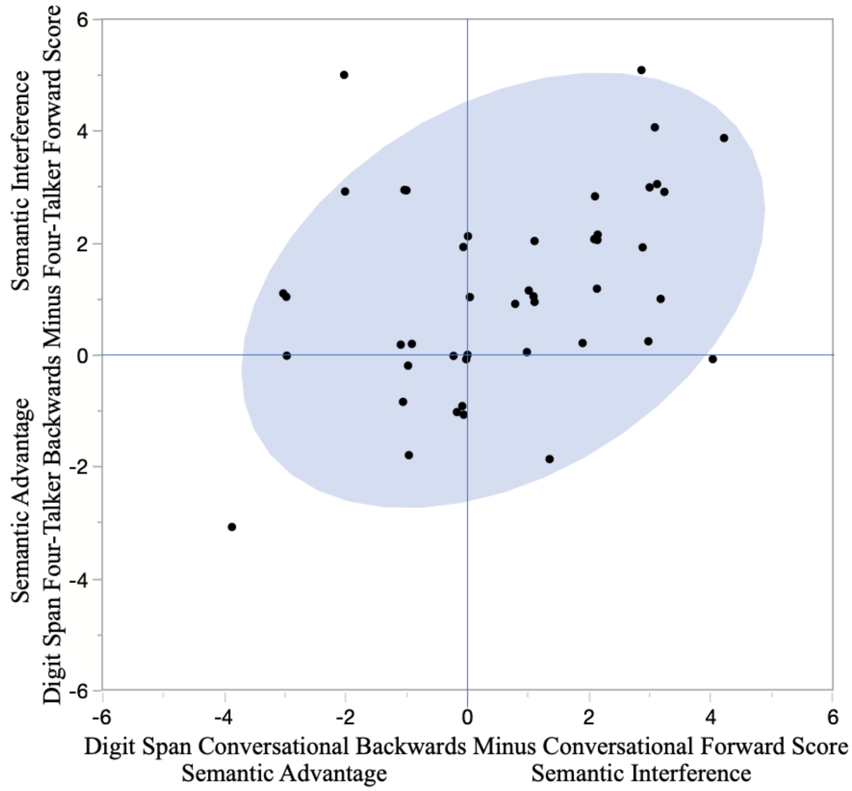

Figure 2. Scatterplot of backwards minus forward masker scores for the conversational masker vs. four- talker conditions (jitter applied for clarity).

Discussion

The purpose of the present study was to determine the effects of listener group and masker condition on auditory memory performance in the presence of noise. The listening conditions were selected specifically to test the effect of semantic information (greatest semantic content in forward conditions) on a memory task. It was hypothesized that the KKS group would perform worse in the Digit Span test. A repeated measures ANOVA revealed no statistically significant main effect for listening group, indicating that self-reported difficulty in understanding speech in noise (KKS group) did not contribute to deteriorated performance on auditory memory tasks as hypothesized. This is contrary to Middelweerd et al. (1990) who reported that the group with speech-in-noise complaints had poorer speech perception in noise thresholds than the control group.

It was also hypothesized that the memory scores would be worse in masking conditions with the greatest semantic content than with less semantic content. The results showed significant evidence of the deteriorating effect of semantic information in masking on auditory memory performance. A post hoc analysis using one sample t-tests also revealed evidence of semantic interference on memory scores. Performance for four-talker backwards was statistically better than the four-talker forward condition (mean difference = 1.13; $p<0.0001$) and the performance for conversational masker backwards was statistically better than the conversational masker forward condition (mean difference= 0.6; $p<0.0001$). Better performance in backwards masking conditions support the second hypothesis that semantic content of maskers would negatively affect auditory memory performance. Greater semantic advantage in conversational masker conditions as seen in better memory scores in conversational masker conditions over all four-talker masker conditions suggests that conversational maskers contain less semantic content by nature.

Clinical Relevance

Working memory is required for many cognitive abilities. Based on the results of the present study, the effect of semantic interference could deteriorate memory performance required in a classroom setting. The maskers chosen mimic common listening environments for school-age children during their required tasks. A measure of semantic interference may be a useful counseling tool to discuss the effects of the listening environment on speech perception in noise ability. It could be used to recommend special accommodations and avoid large group settings when significant memory performance in a task or communication is required.

One important question that may be brought up when discussing these results is: what is the relationship to an auditory processing disorder (APD). Is APD affecting subjects who are performing worse during memory tasks in the presence of linguistically-meaningful maskers? Although a speech recognition in noise disorder is considered characteristic of APD, it is not consistently found that people with APD do poorer than a control group without APD on speech-in-noise tests (Vermiglio, 2014). Because of the ambiguity of APD, it is not possible to determine if it is a potential factor contributing to the results of this study.

Study Limitations

Due to a limited age range in this sample, the results of this study cannot be generalized to older populations. In the original pilot study, the Digit Span in reverse condition was administered and floor effects were observed. The authors hypothesize that the signal-to-noise ratio may have contributed to the floor effects in reverse condition. Additionally, it is interesting to note that semantic interference varies from person to person.

Future Studies

It is recommended that future research be conducted to investigate factors which could contribute to variable semantic interference such as personality characteristics including neuroticism (predisposition to stress), openness (an individual's curiosity for outside information), and extraversion (tendency to focus outward). Future studies should compare speech-in-noise abilities and other working memory measures. It would also be interesting to further analyze the present study's data to determine the relationship between self-reported speech-in-noise difficulties and speech perception in noise test results.

Conclusion

The results of the present investigation revealed no statistically significant main effect for participant group on Digit Span scores. A significant main effect for listening condition was found. Evidence of semantic interference was demonstrated by statistically significantly better scores in backwards masking conditions than forward conditions. This suggests that memory ability may be compromised in the presence of background noise containing semantic information. Conditions containing greater semantic information may have contributed to greater deterioration of auditory memory performance.

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