The Relationship Between Self-Perceived Hearing Ability and Listening-Related Fatigue

Undergraduate Research Thesis

Presented in partial fulfillment of the requirements for graduation
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by

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Abstract

Background

Many adults experience hearing problems despite a diagnosis of normal hearing. An invalidation of self-perceived hearing problems can be emotionally distressing. Previous research describes a normal hearing test with perceived trouble understanding speech-in-noise as hearing difficulties (HD). Additionally, an individual's reported listening-related fatigue is associated more with their perceived HD than their degree of hearing loss.

Recent studies investigated factors that contribute to deficits in speech-in-noise performance, a common symptom of HD. Specifically, adults with poorer working memory and poorer extended high-frequency (EHF) hearing exhibited poorer speech-in-noise performance than adults with better working memory and better EHF hearing.

Purpose

The primary purpose of this thesis was to examine the relationship between auditory working memory, EHF thresholds, speech-in-noise performance, and the perception of one's HD. A secondary purpose was to understand the influence of listening-related fatigue, effort, and the perception of one's HD. By confirming auditory deficits via clinical test results, individuals can be counseled and treated more effectively.

Methods

Participants were 17 adults (ages 18 – 58 years of age, 3 males, 14 females) with normal to "near normal hearing" as defined by Moore et al. (2012). Self-perceived HD were determined by the Adult Auditory Performance Scale (AAPS; Roup et al., 2021). The Word Auditory Recognition and Recall Measure (WARRM; Smith et al., 2016) was used to evaluate auditory working memory. Listening-related fatigue was assessed with the Vanderbilt Fatigue Scale for

Adults (VFS-A; Hornsby et al., 2021) and listening effort was evaluated with the National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988) in order to assess their potential relationship with self-perceived HD.

Results

Results revealed significant correlations between self-reported HD and listening-related fatigue for the total and cognitive domain VFS-A scores. Specifically, adults with greater degrees of HD also reported greater degrees of listening-related fatigue. In addition, results revealed that listening-related fatigue and listening effort (i.e., mental demand) were significantly correlated, meaning when adults experienced greater listening-related fatigue from auditory situations, they had to exert more effort. Of the auditory tests administered, participants reported that pure-tone detection required much less effort than the other auditory tasks. This illustrates that the typical hearing test is a relatively low effort task that does not compare to the everyday auditory situations of adults' lives.

Conclusions

Results from the present study suggest that it is essential to employ more rigorous tests of auditory function that are more representative of everyday listening (e.g., auditory and cognitive resources) to more accurately assess an individual's hearing ability and validate their self-perception of HD.

Acknowledgments

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Introduction and Literature Review

Normal hearing is defined as the ability to hear low-intensity pure tones in the frequency region important for speech understanding (i.e., 250 – 8000 Hz ≤ 25 dB HL; Clark, 1981). Many individuals meet the requirements of normal hearing, yet some of these individuals still greatly struggle to understand speech-in-noise (Saunders & Haggard, 1989). Roughly 12% of individuals with normal pure-tone detection thresholds struggle to hear in background noise (Tremblay et al., 2015). For the purposes of this study, individuals that struggle to hear and understand speech-in-noise despite normal pure-tone detection thresholds will be referred to as individuals with HD. Previous research suggests that one fourth of audiologists encounter at least four adults per month with HD (Koerner et al., 2020).

Identification of individuals with HD is crucial because these individuals are at risk for emotional distress and self-imposed restrictions on social engagement (Gopinath et al., 2011). They are more likely to report symptoms associated with depression (Tremblay et al., 2015). Those that report more self-perceived difficulty hearing also report more listening-related fatigue (Alhanbali et al., 2018; Hornsby & Kipp, 2016). Additionally, an individual's reported listening-related fatigue is associated more with their perceived HD rather than their degree of hearing loss (Hornsby & Kipp, 2016). Listening-related fatigue can interfere with self-care activities and quality of life (Evans & Wickstrom, 1999). In addition to listening-related fatigue, adults that perceive noisy situations as a demanding task likely exhibit greater effort and psychophysiological responses consistent with the activation of a stress response (Mackersie & Cones, 2011).

HD goes undetected by standard hearing tests (Badri et al., 2011) as well as other standard measures of auditory function such as otoacoustic emissions or word recognition tests (Tremblay et al., 2015). In contrast, HD have been shown to be significantly correlated with speech-in-noise performance such that individuals with greater degrees of HD perform poorer on speech-in-noise tasks (Roup et al., 2021; Saunders & Haggard, 1989). Detection and validation of the struggle to understand speech-in-noise is essential to the rehabilitation and wellbeing of adults experiencing HD. To diagnose HD clinically, it is essential to assess the contributions of potential underlying auditory deficits to speech-in-noise performance.

Extended High Frequencies

The typical hearing test only includes frequencies from 250 – 8000 Hz, however, the range of human hearing extends up to 20,000 Hz. The frequencies above 8000 Hz are commonly called extended high frequencies (EHF). EHF hearing is thought to provide some auditory information such as localization of sounds and speech recognition (Monson et al., 2019). Several studies have found that EHF hearing can be a predictor of speech-in-noise performance (Yeend et al., 2016; Monson et al., 2019; Mishra et al. 2022). For example, Yeend et al. (2019) found that adults with poorer EHF thresholds exhibited worse performance on speech-in-noise tasks compared to adults with better EHF hearing. Similarly, Polspoel et al. (2022) established that speech-in-noise performance improved when speech information above 8000 Hz was available to the listener. Polspoel et al. observed this by presenting stimuli in three conditions: 1) unfiltered speech and noise, 2) unfiltered speech with noise low-pass filtered at 8000 Hz, and 3) both speech and noise low-pass filtered at 8000 Hz. Listeners achieved better speech recognition scores when the noise was low pass filtered but the speech was left unfiltered. Listeners scored lowest in speech recognition when both speech and noise were low pass filtered at 8000 Hz, suggesting that frequencies greater than 8000 Hz contribute to speech recognition.

Previous research suggests that EHF hearing impairment is not uncommon. Motlagh Zadeh et al. (2019) reported 56% of adults had hearing impairment above 8000 Hz despite normal pure-tone detection thresholds from 250 - 8000 Hz. Of the 56% with impairment, Motlagh Zadeh et al. found that 64% of adults reported HD. Motlagh Zadeh et al. (2019) did not consider age in their evaluation of EHF hearing impairment. When age was included in analysis, Mishra et al. (2022) found that only 19% of participants had EHF hearing impairment despite normal hearing from 250 – 8000 Hz.

Poor EHF thresholds can indicate poor cochlear health and provide an early warning sign of cochlear pathology. Frequencies above 8000 Hz are stimulated in the basal region of the cochlea which is particularly susceptible to the effects of aging, disease, ototoxic drugs, and noise exposure (Lough & Plack, 2022; Mishra et al., 2022). Mishra et al. (2022) observed that poor EHF thresholds might reveal signs of early auditory aging and might be due to risk factors such as head trauma, noise exposure, or autoimmune disorders. EHF thresholds are not typically measured in standard audiometry (Lough & Plack, 2022), therefore a deficit in EHF hearing may go undetected by during routine clinical testing. Therefore, evaluation of EHF hearing may provide insight into the causes of HD.

Working Memory

Working memory is a cognitive process and refers to the ability to store information over a short period of time and then to retrieve and use that information at a later point in time (Gordon-Salant & Fitzgibbons, 1997). Non-auditory working memory is a significant predictor of the ability to understand speech in noisy backgrounds (James et al., 2014; Vermeire et al., 2019; Yeend et al., 2019). For example, Vermeire et al. (2019) measured working memory with a reading span test. Participants with worse working memory capacity scores (worse reading span scores) had more difficulty understanding sentences in noise than adults with better working memory performance. This direct correlation may be due to a reallocation of cognitive resources. Pichora-Fuller et al.

(1995) postulated that in difficult listening situations, individuals must reallocate resources to process several different sources of sound, leaving less resources available to more central cognitive processes such as the processes involved in working memory (e.g., storage and retrieval of auditory information).

Non-auditory working memory is typically measured with the reading span test, which is a visual working memory task. In everyday listening situations individuals often need to store and utilize auditory information in addition to visual information, thus an auditory working memory task may be more appropriate to evaluate those with HD. Auditory working memory has been shown to be related to speech perception in noise (Ingvalson et al., 2015). Specifically, when an individual improved their auditory working memory capacity training, their speech perception in noise performance improved. Training consisted of an auditory digit span test that changed in length based upon listener ability. The first two training days were done in quiet, then the next two in noise, and the final training days were completed with non-speech distractors and noise of various signal-to-noise ratios. In both English and Mandarin, this working memory training improved speech perception in noise (Ingvalson et al., 2015). There have been many different approaches to measuring auditory working memory ability, such as measuring listening span (Gordon-Salant & Cole, 2016; Gordon-Salant & Fitzgibbons, 1997) and ability to remember the frequency of one tone and match it to later played tones (Lad et al., 2020). Individuals with poorer working memory, measured by listening span, performed worse in noise than individuals with better working memory, consistent with conclusions drawn from studies based on reading span (Gordon-Salant & Cole, 2016; Gordon-Salant & Fitzgibbons, 1997). Lad et al. (2020) targeted auditory working memory in a unique way: in each trial, participants heard a pure tone that differed in frequency modulation (400 – 1000 Hz). Then participants manually increased or decreased the frequency of a second tone until they believed it matched the frequency of the first tone they heard. Lad et al. (2020) found that adults who were able to match the frequency of the two tones more often, consistent with stronger auditory working memory, also had better speech-in-noise thresholds. Although the above measures target an auditory domain, they can be somewhat time-consuming, clinically difficult, and may depend on literacy or mathematical skills. Assessment of working memory capacity to identify possible factors contributing to speech-in-noise difficulties for adults with normal pure-tone hearing requires a clinically feasible, auditory-targeted working memory task. One auditory working memory test that shows clinical potential is the Word Auditory Recognition and Recall Measure (WARRM; Smith et al., 2016). The WARRM utilizes 100 monosyllabic words commonly used on speech-recognition tests to measure word recognition and auditory working memory within the same test. WARRM recall scores have been reported to be significantly correlated with other memory measures suggesting strong test validity (Smith et al., 2016). The WARRM exists in an abbreviated format (Smith et al., 2020) offering a time-sensitive clinical option. When the WARRM was administered to young normal hearing listeners, older normal hearing listeners, and older listeners with hearing loss, the older listeners with hearing loss had significantly worse recall scores than the other two listener groups (Smith et al., 2016). The performance of adults with HD on the WARRM has yet to be evaluated.

Listening-Related Fatigue

Fatigue can be a consequence of continuous mental work. Fatigue that is more frequent, severe, and brought about by everyday activities can have significant negative effects on quality of life (Hornsby & Kipp, 2016). Given the negative effects that fatigue may have on a population, it is important to assess listening-related fatigue for the population experiencing HD. Previous research has found that adults with greater HD also report greater listening-related fatigue

(Hornsby & Kipp, 2016). To evaluate HD, Hornsby and Kipp (2016) used the Hearing Handicap Inventory for the Elderly which is a 25-item questionnaire that measures self-reported perception of HD in the social and emotional domains. Listening-related fatigue was subjectively measured as well through the Profile of Mood States (McNair et al., 1971; which addresses several emotional states of fatigue) and the Multidimensional Fatigue Symptom Inventory-Short Form (Stein et al., 2004; which addresses general, physical, emotional, and mental states of fatigue). Similar results were obtained by Alhanbali et al. (2017), who also utilized the Hearing Handicap Inventory for the Elderly to measure HD. Alhanbali et al. found that HD were associated with higher levels of self-reported fatigue than individuals who reported no HD. To evaluate fatigue, the Fatigue Assessment Scale, a 10-item questionnaire requiring participants to rate how they feel on a daily basis, was utilized. To understand the relationship between fatigue and HD in the current study, it is important to use a fatigue assessment designed to target fatigue specifically related to listening. Hornsby et al. developed the Vanderbilt Fatigue Scale for Adults (VFS-A; Hornsby et al., 2021) to be a multidimensional fatigue scale aimed at assessing listening-related fatigue. The 40-item questionnaire measures listening-related fatigue in the physical, mental, emotional, and social domains. Preliminary results from this questionnaire indicate age-related differences in listening-related fatigue only in the social domain (i.e., greater listening-related fatigue with greater age; McGarrigle et al., 2021).

Listening-Related Effort

Listening-related fatigue is closely tied to listening-related effort. HD can be particularly impairing in noisy situations where more than one person is speaking. Previous research suggests that more listening-related effort is exerted during a multiple speaker task (Mackersie & Cones, 2011). Mackersie and Cones measured objective effort through heart rate, skin conductance, skin temperature and electromyographic activity. Following a speech recognition task, subjective measure was also recorded utilizing the National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988) questionnaire. As task difficulty increased (i.e., more than one talker speaking at the same time), skin conductance and electromyographic activity also increased. Participants that rated a task high in subjective effort (i.e., effort increased by a factor of at least 4.5 as compared to other tasks) also showed significant changes in skin conductance. Greater subjective effort ratings with increased skin conductance suggests that subjective forms of listening-related effort reflect physiologic measures of effort. Alhanbali et al. (2018) found that subjective everyday listening-related effort was associated with higher levels of reported HD. To measure subjective effort, Alhanbali used the Effort Assessment Scale, a 6-item questionnaire with three effort-based questions from the Speech, Spatial Quality Hearing Scale developed by Gatehouse and Noble (2004). The Effort Assessment Scale requires participants to rate their effort on a visual analogue scale from 0 (no effort) to 10 (lots of effort) in response to prompts about the task. The prompts specifically target listening-related effort with statements such as "How much effort do you have to concentrate when listening to someone?" and "Do you have to put in a lot of effort to hear what is being said in a conversation with others?". In contrast to the study performed by Mackersie and Cones (2011) who measured listening-related effort associated with a specific task, Alhanbali surveyed listening-related effort related to one's everyday life. In the present study, similar to Mackersie and Cones, listening-related effort was measured in response to specific auditory tasks to understand the exertion required to complete tests that might be used in the clinic.

Purpose and Significance of This Study

The purpose of the current study was to evaluate the relationship between self-reported HD, EHF hearing, auditory working memory and speech-in-noise performance. Specifically, this study aimed to identify any patterns between EHF hearing, auditory working memory and speech-in-noise performance to adapt as diagnostic criterion for individuals reporting HD. The central hypothesis was that individuals with self-reported difficulty in noise will have poorer EHF threshold results, poorer auditory working memory, and greater listening-related fatigue and listening effort compared to those with normal hearing that do not report difficulty in noise.

Methods

Participants

Participants were 17 adults (18-58 years of age, 3 male, 14 female) with pure-tone thresholds from 250 – 8000 Hz within the normal range (≤ 20 dB HL) or "near-normal" range as defined by Moore et al. (2012). Near-normal hearing was defined by Moore et al. (2012) to be ≤ 25 dB HL from 250 – 2000 Hz, ≤ 30 dB HL up to 3000 Hz, ≤ 35 dB up to 4000 Hz, and ≤ 40 dB HL up to 6000 Hz. Further inclusion criteria included normal otoscopy, normal tympanometry, and native speakers of American English. Written consent was obtained from all subjects prior to participation in this study. This study was approved by the Institutional Review Board at The Ohio State University.

Materials

Questionnaires

Self-perceived HD were assessed with the Adult Auditory Performance Scale (AAPS; Roup et al., 2021). The AAPS is a 36-item questionnaire that assesses listening difficulty across six listening conditions (quiet, ideal, noise, multiple inputs, auditory memory and sequencing, and auditory attention span). Participants rate their ability to hear in each environment on a scale from 0 to 6. Rating an AAPS item with a 0 means the participant never struggles to hear in the prompted situation. In contrast, rating an AAPS item with a 6 means the participant believes that they always struggle to hear in the prompted situation. The AAPS can be scored with a total (i.e., Global) score or in smaller subscales based on the six listening conditions. Higher scores, either global or subscale, indicate greater self-perceived HD.

Self-perceived listening-related fatigue was assessed using the Vanderbilt Fatigue Scale for Adults (VFS-A; Hornsby et al., 2021). The VFS-A is a 40-item scale that assesses self-perceived listening-related fatigue in four domains: physical, mental/cognitive, emotion, and social. Each item of the VFS-A prompts the participant to rate the statement from 0 to 4, with 0 meaning that the participant never reacts in the way that the statement describes and 4 meaning that the participant always has the reaction described in that item of the questionnaire. The VFS-A can be summed into a total score or in sub-scores referring to each of the four domains. For both total and sub-scores, a greater the score indicates greater self-perceived listening-related fatigue. The VFS-A has been shown to differentiate between young and older listeners with hearing loss in the social domain using a preliminary version (McGarrigle et al., 2021). Specifically, older listeners with hearing loss scored higher on the VFS-A, consistent with greater self-perceived listening-related fatigue.

Listening effort was assessed using the National Aeronautics and Space Administration Task Load Index (NASA-TLX; Hart & Staveland, 1988). Through a visual analog scale, the NASA-TLX requires participants to rate the amount of effort they feel they exerted during the previous task. Participants score their perceived exertion of effort in six dimensions: mental, physical, temporal, effort, performance, and frustration. Higher scores (i.e., scores marked more towards the right of the analog scale) indicate more perceived exertion of effort in that domain. Though the NASA-TLX can be scored in a total or averaged effort score, only the subscores were utilized for this study.

Behavioral Measures

Speech-in-spatialized noise performance was measured using the Listening in Spatialized Noise – Sentences Test (LiSN-S; Cameron & Dillon, 2007). The LiSN-S determines speech recognition thresholds (SRT) across four conditions. The target sentences spoken by a female speaker are always presented at 0° azimuth (under headphones using head-related transfer functions). The background discourse spoken by the same or different female speaker is presented in one of two locations: 0° and $\pm 90^{\circ}$ azimuth. Therefore, the four conditions of target to masker are: same voice at 0°, same voice at $\pm 90^{\circ}$, different voices at 0°, and different voices at $\pm 90^{\circ}$. Participants were asked to repeat as many words as possible in each target sentence. The test adapts, adjusting the signal-to-noise ratio (SNR) based on the number of correctly recalled words in the previous sentence. When a participant correctly recalls most of the words from the sentence, the SNR decreases. When the participant cannot correctly recall the words in the target sentences, the SNR increases. The conditions were presented to the listener in the following order: DV90, SV90, DV0, SV0 (Cameron & Dillon, 2007). The LiSN-S scores the listener's speech-in-noise performance in each condition and in three advantage scores: talker, spatial and total. Higher scores indicate worse speech-in-noise performance and more reliance on other cues (i.e., talker, spatial or SNR cues).

Auditory working memory was assessed using the Word Auditory Recognition and Recall Measure (WARRM; Smith et al., 2016). The WARRM utilizes 100 monosyllabic words commonly used on speech-recognition tests to yield two measures: word recognition and auditory working memory. Target words are presented in different set sizes (2, 3, 4, 5, and 6 words) with 5 trials in each set. Each word is presented following a carrier phrase ("You will cite") in a quiet environment. The task is to repeat the words in each set after a recall prompt. There is a processing task during the recall measure to engage cognition. During this condition, participants must identify if the first letter of each word belongs to the first half of the alphabet or the second half of the alphabet. There is an equal distribution of words beginning with letters from each half of the alphabet in every word set. Scores on the alphabet processing task are expected to be nearly perfect to assure engagement. The WARRM produces three measures: a word recognition score, a recall score, and a span score. The word recognition score consists of an overall percent correct of the 100 words. The recall score is calculated based on the percentage of words the participant correctly recalls. The span score depicts the maximum set size where participants recall at least 3 out of the 5 trials correctly. If there is no response for the recall of a word, then the word is scored as incorrect.

Procedures

A case history, the AAPS, and the VFS-A were completed prior to any audiometric testing. Otoscopy, tympanometry, and acoustic reflex thresholds were measured prior to pure-tone threshold testing. If acoustic reflex thresholds could not be obtained, bone conduction audiometric testing was performed after air conduction audiometry. For all participants, pure-tone thresholds were measured for 250 Hz – 8000 Hz. EHF thresholds were measured for 10, 12.5, 14, and 16 kHz. The NASA-TLX was administered four times throughout the study: 1) after the hearing test, 2) after the working memory task (WARRM), 3) after the speech-in-noise task (LiSN) and 4) at the conclusion of the study.

Audiometric testing including the hearing test, EHFs, and the WARRM, was conducted in a sound-attenuating booth using a Grason-Stadler AudioStar and high-frequency circumaural headphones (Sennheiser HAD 300). The WARRM was presented binaurally at a level of 50 dB HL. The LiSN-S was presented through circumaural headphones (Sennheiser HD 215) from a computer program routed through an external soundcard. The testing order of the WARRM and LiSN-S was counterbalanced across participants.

Results

Hearing Thresholds and Self-Perception of Hearing Ability

Participants exhibited normal to near-normal hearing in the standard audiometric range, whereas EHF hearing thresholds varied, as depicted in Figure 1. Most participant EHF thresholds (n = 9) were not greater than 20 dB HL. In contrast, a minority of participants (n = 6) had a sloping mild-to-moderate loss in the EHF range. A few participants (n =2), depicted with a star in Figure 1, did not respond at the intensity limits of the audiometer for some EHF. Participant self-perception of hearing ability (Global AAPS scores) revealed participants had minimal to no HD [re: Roup et al. (2021); range: 0.111 – 2.333, median: 0.875, average: 0.972]. Table 1 presents participant AAPS scores for the Global and Noise domains. Table 2 presents participant self-perception of listening-related fatigue (VFS-A scores). The scores of self-perceived total listening-related fatigue scores ranged from 1 – 67 with a median of 28 and an average score of 28.

Self-Perceived Listening-Related Fatigue and Speech-In-Noise Performance

To evaluate the relationship between self-perceived listening-related fatigue and speech-in-noise performance, Pearson's correlational analyses were performed. A significant negative correlation was observed between listening-related fatigue and LiSN-S talker advantage ($r = -0.58$; $p = 0.02$; Figure 2). As participants perceived more listening-related fatigue in their everyday lives, they also struggled to benefit from talker cues as much as participants that did not perceive as much listening-related fatigue. A similar relationship was observed when the relationship between listening-related fatigue in the cognitive domain and LiSN-S talker advantage scores were evaluated. Figure 3 depicts the significant negative correlation between listening-related fatigue (cognitive domain) and LiSN-S talker advantage ($r = -0.53$; $p = 0.03$). When participants perceived

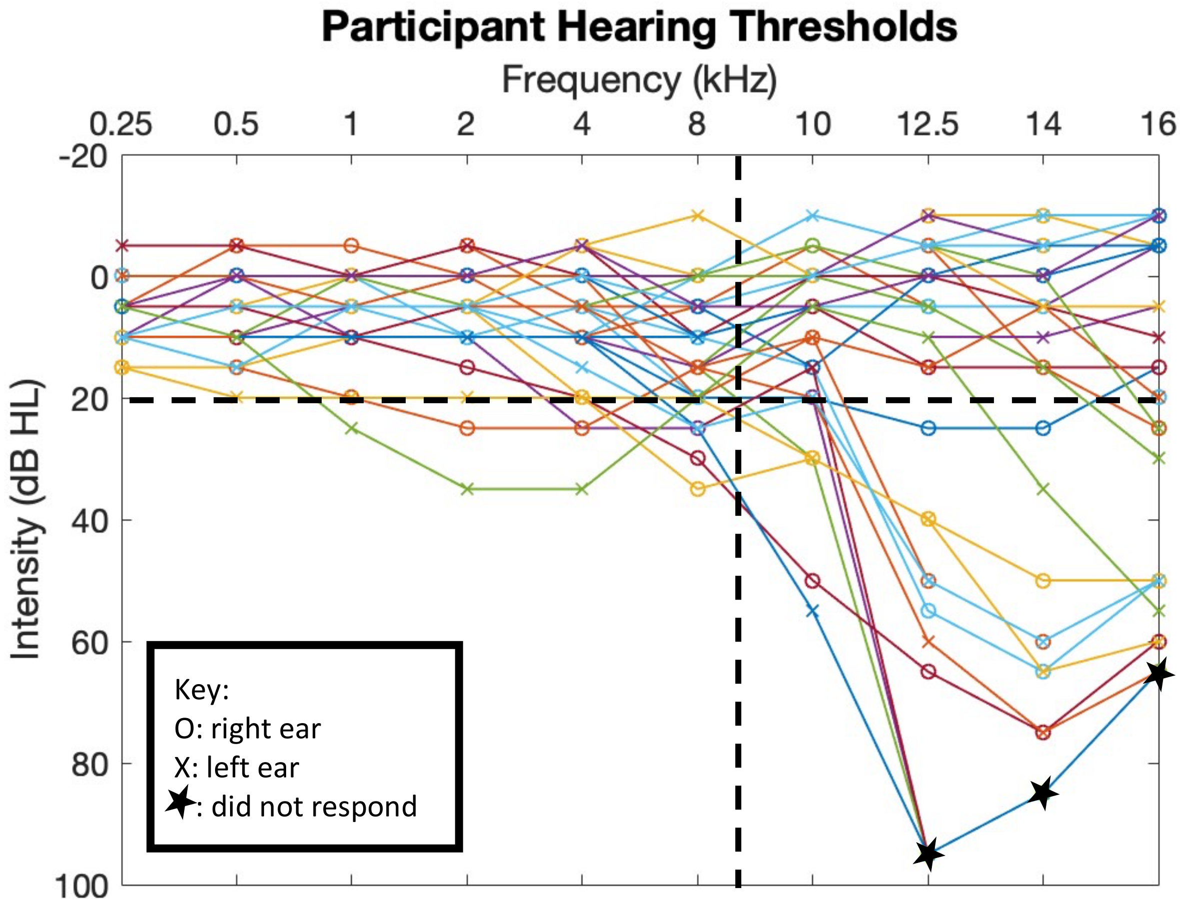

Figure 1: Individual right and left ear thresholds (dB HL) for .25 – 16 kHz for all participants. The vertical dashed line separates standard hearing test frequencies from EHF. The horizontal dashed line denotes 20 dB HL. The stars indicate where participants did not respond at the intensity limits of the audiometer.

Table 1: AAPS Global and Noise scores for all participants.

Sub. ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Global	1.7	0.7	0.5	0.6	0.1	1.3	1.2	1.1	0.7	0.6	2.3	0.1	0.1	1.3	1.5	0.5	0.7
Noise	2.7	0.7	2.4	1	0.1	2	1.7	1.7	0.4	1.4	4.4	0	2.1	1.8	2.4	0.4	1.5

Table 2: VFS-A Total and Cognitive scores for all participants.

Sub. ID	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Total	42	43	4	10	1	41	28	28	20	48	67	2	10	60	41	10	18
Cognitive	14	17	2	2	1	11	16	15	10	15	22	1	6	17	15	3	11

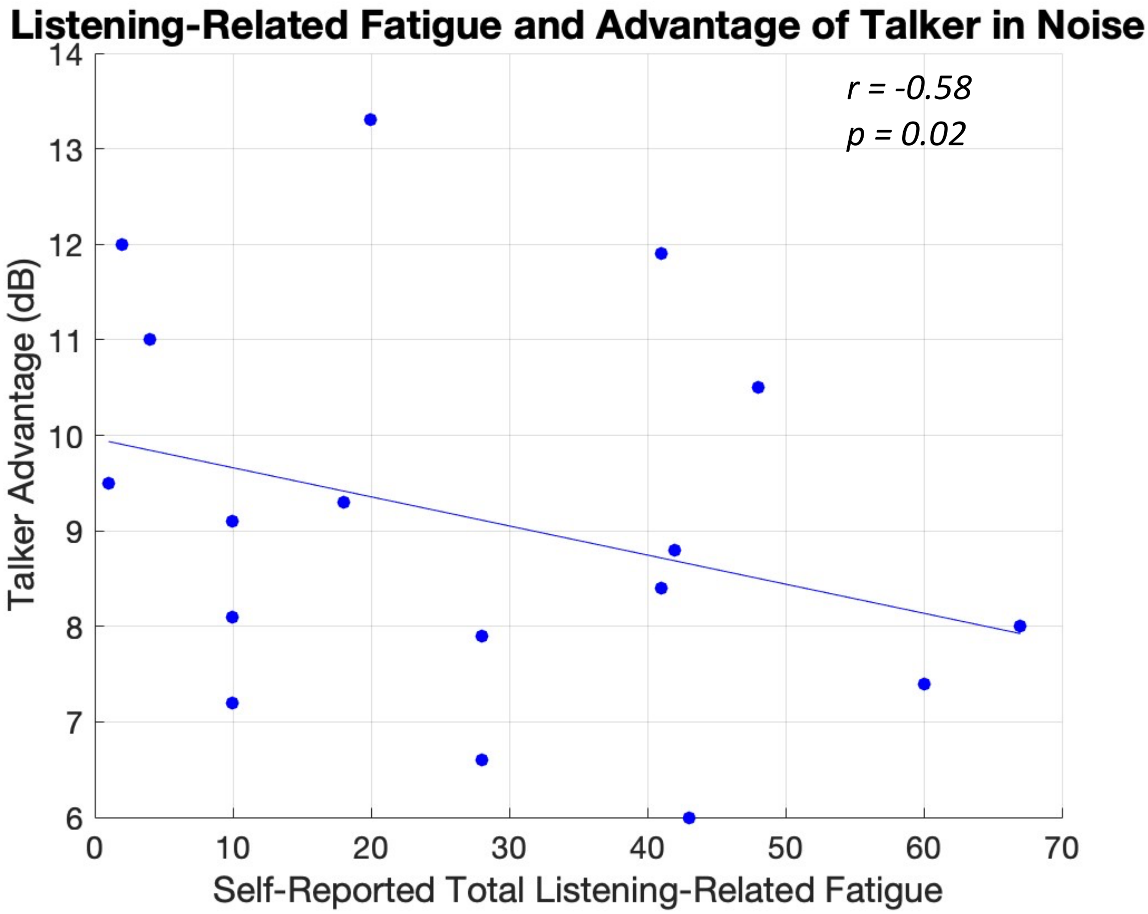

Figure 2: LiSN-S: Talker Advantage as a function of self-perceived total listening-related fatigue scores. The line represents regression from the mean. Significant negative correlations were observed between the LiSN-S: Talker Advantage and VFS-A total scores.

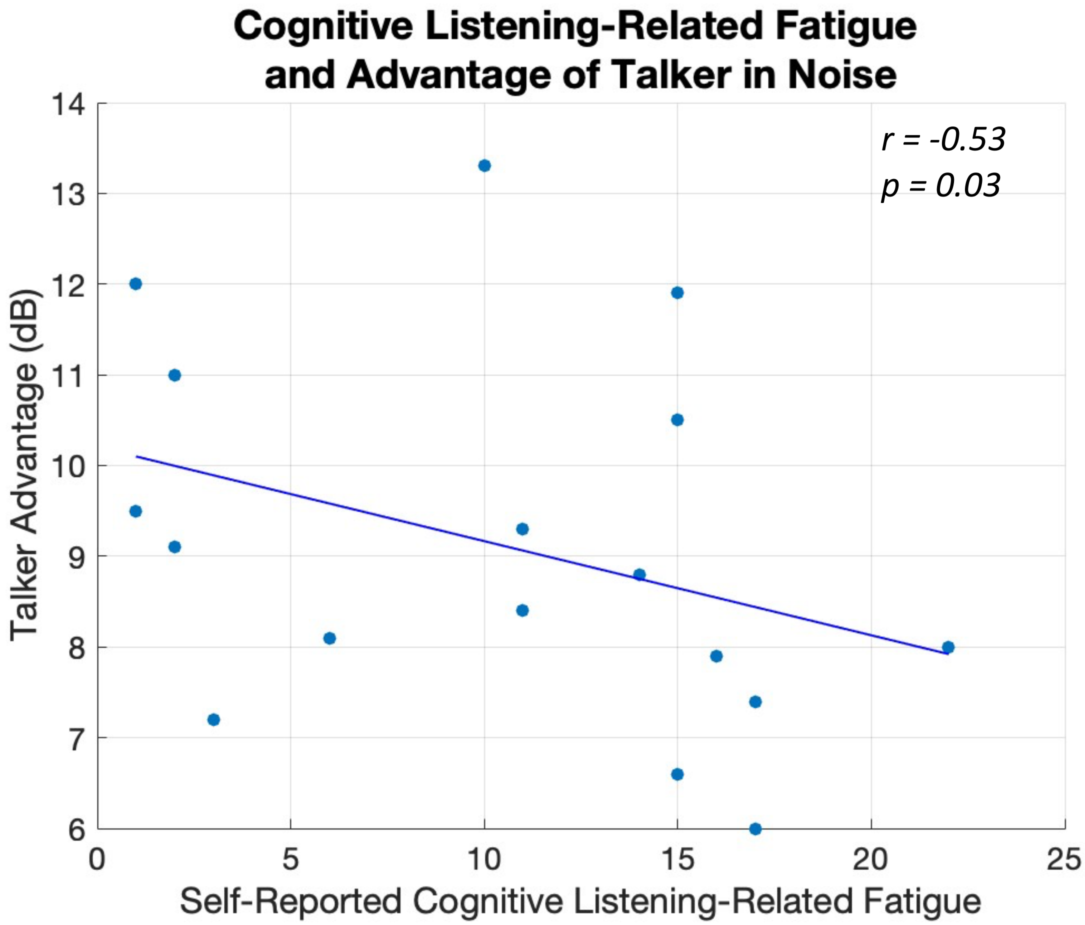

Figure 3: LiSN-S: Talker Advantage as a function of self-perceived listening-related fatigue in the cognitive domain. The line represents regression from the mean. Significant negative correlations were observed between the LiSN-S: Talker Advantage and VFS-A cognitive scores.

more listening-related fatigue in a cognitive domain from their everyday lives, they tended to struggle to benefit from talker cues in noisy situations to the same degree as those that did not perceive such cognitive listening-related fatigue. Relationships between VFS-A scores and other LiSN-S measures (i.e., DV90, DV0, SV90, SV0, and Spatial Advantage) were evaluated but not found to be significant.

Self-Perceived Hearing Ability and Listening-Related Fatigue

Evaluation of the relationship between self-perceived hearing ability and self-perceived listening-related fatigue revealed a strong significant positive correlation for both total listening-related fatigue (r = 0.77; $p < 0.001$) and cognitive listening-related fatigue (r = 0.77; $p < 0.001$) respectively (see Figure 4). When participants perceived more difficulty hearing they also tended to perceive a greater amount of total and specifically, cognitive listening-related fatigue in their everyday lives.

Similarly, the relationship between self-perceived HD in noise and self-perceived listening-related fatigue was found to be a significant positive correlation for both total listening-related fatigue (r = 0.64; $p = 0.004$) and cognitive listening-related fatigue (r = 0.63; $p = 0.005$) respectively (see Figure 5). When participants perceived more HD in noise, they also tended to experience more listening-related fatigue (total and cognitive) in their everyday lives.

Self-Percieved Hearing Ability, Effort and Frustration

A positive trend was observed between self-percieved hearing ability and self-percieved effort and frustration during complex auditory tasks. Figure 6 depicts the significant positive relationship between self-percieved hearing ability and NASA-TLX scored effort (r = 0.48; $p = 0.04$) and frustration (r = 0.65; $p = 0.005$) respectively. When participants felt that they struggled more to hear, they tended to feel that they exerted more effort during the complex auditory tasks

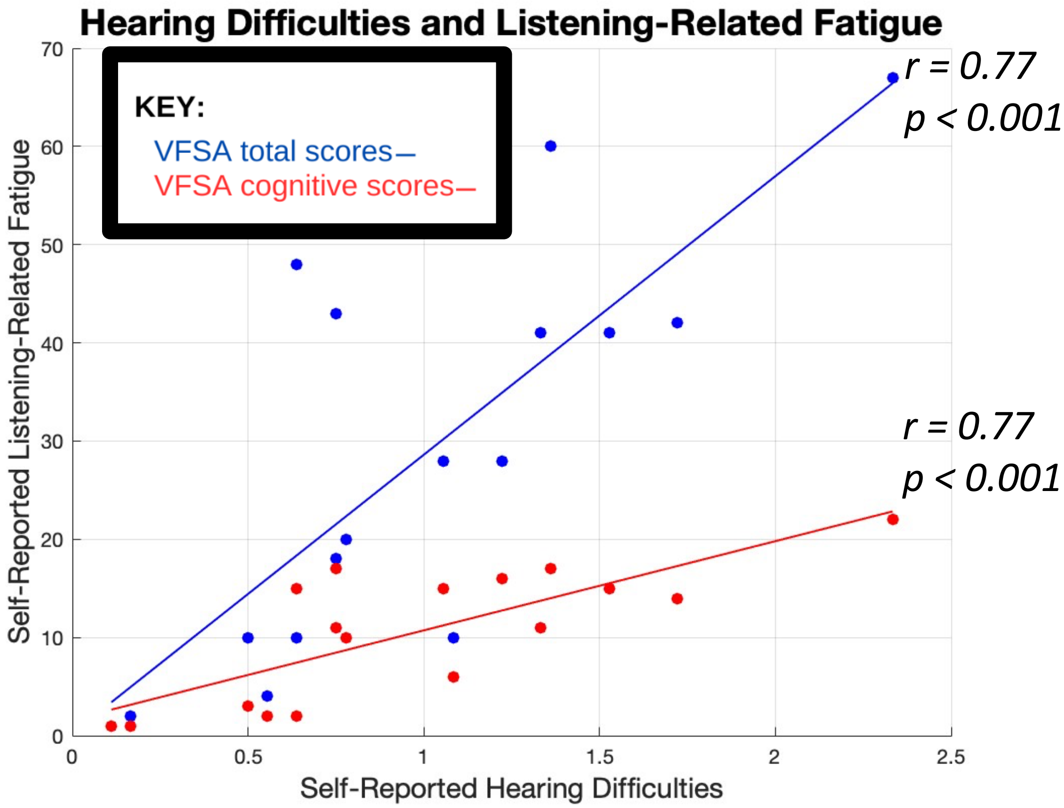

Figure 4: Self-perceived listening-related fatigue (VFS-A) as a function of self-perceived hearing ability (AAPS). The line represents regression from the mean. Significant positive correlations were observed between VFS-A total and cognitive scores and AAPS scores.

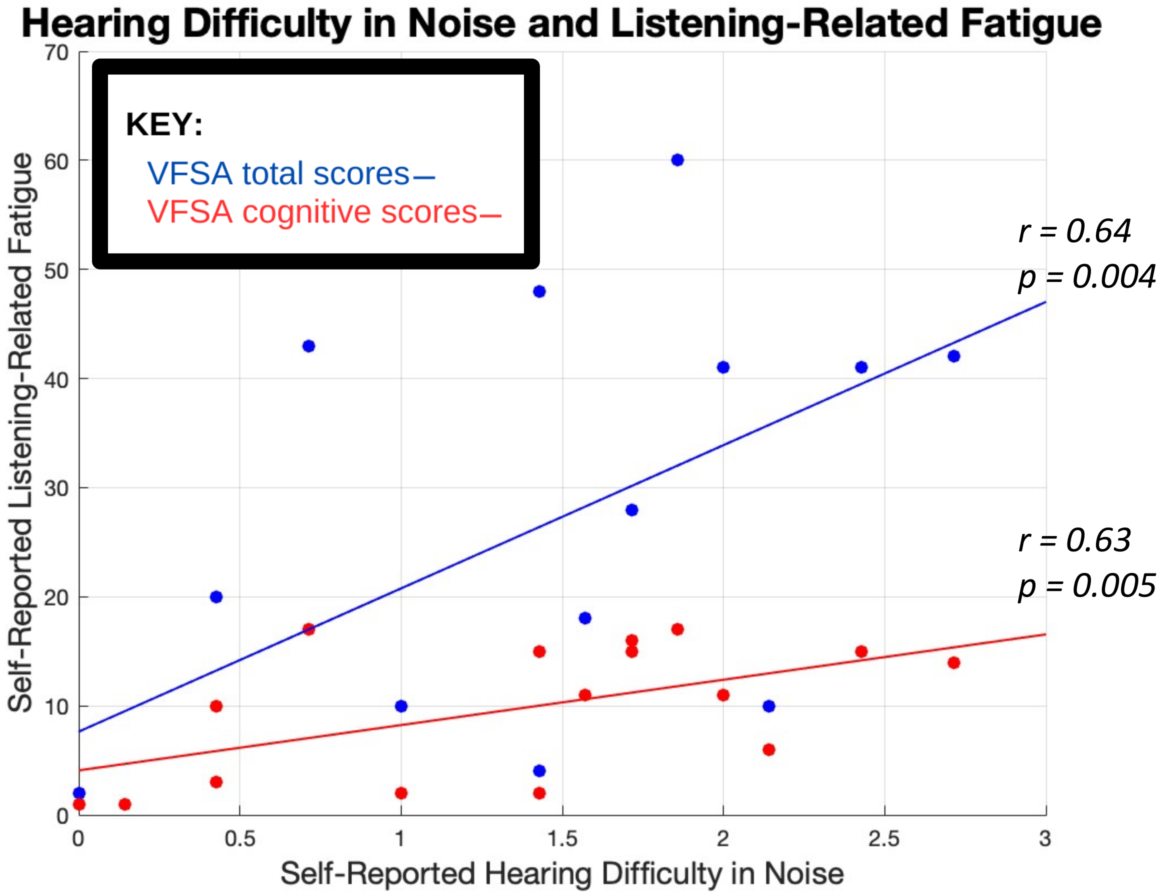

Figure 5: Self-perceived listening-related fatigue (VFS-A) as a function of self-perceived hearing ability (AAPS) in noise. The line represents regression from the mean. Significant positive correlations were observed between VFS-A total and cognitive scores and AAPS noise subscale scores.

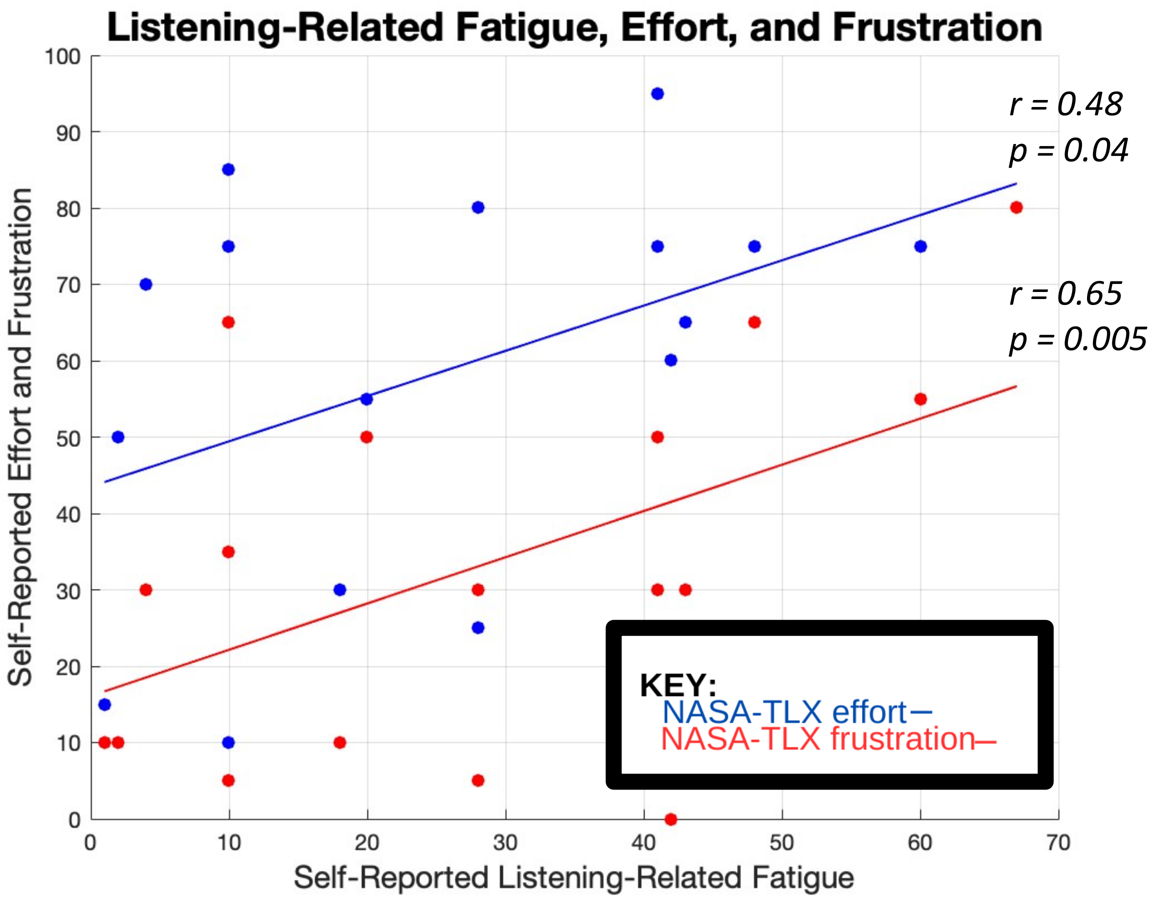

Figure 6: Self-perceived effort and frustration (NASA-TLX) as a function of self-perceived listening-related fatigue (VFS-A). The line represents regression from the mean. Significant positive correlations were observed between NASA-TLX post-test effort and VFS-A total scores and between NASA-TLX post-test frustration and VFS-A total scores.

(WARRM and LiSN) of this study. They also felt more frustrated during those auditory tasks that prompted working memory and exposed the participant to noisy situations.

Discussion

The present study evaluated the relationship between auditory working memory, EHF thresholds, speech-in-noise performance, and the perception of one's HD. It was hypothesized that auditory working memory and EHF thresholds would predict speech-in-noise performance. However, this relationship was not observed. In this data set, only one participant reported an AAPS score (noise subscale = 4.4) that would be considered abnormal (re: Roup et al., 2021) in terms of the difficulty one perceives listening in noise. If more participants were recruited and if more participants reported greater degrees of HD, it might be possible to replicate the predictive relationship observed by Yeend et al. (2019). Although only one participant's AAPS score qualified as abnormal, analysis of speech-in-noise performance, self-reported listening-related fatigue, and the perception of one's HD revealed significant relationships.

Results revealed a significant negative relationship between self-perceived listening-related fatigue (total and cognitive) and the LiSN-S Talker advantage. Participants that reported more listening-related fatigue in their daily lives did not benefit as much from talker cues in noisy environments as participants that did not report as much listening-related fatigue. The LiSN-S has different talker conditions. In one condition, the noise and the target sentence are provided by the same voice. In another condition, the noise and the speech are provided by two different female voices. Talker advantage defines the benefit in signal-to-noise ratio gained when talker cues such as two different voices are provided (Cameron & Dillon, 2007). In theory, the talker advantage should allow someone to perform better in a noisy situation when there are two different speakers, meaning that their talker advantage increases. When someone cannot distinguish speaker cues, their talker advantage score will be lower because they cannot utilize the different voices of the talkers as much to hear the target sentences in noise. In this data set, as fatigue increased, talker advantage decreased, consistent with less benefit from speaker cues. This finding supports the results of Davis et al. (2020) who found that individuals struggling to hear and understand speech felt that it was tiring to try and pay attention to the vocal characteristics of the speaker. Davis et al. (2020) also stated that many participants felt that trying to listen and understand speech in difficult listening environments increased the likelihood of developing listening-related fatigue. Further research needs to take place to establish a causal relationship between listening in noise and listening-related fatigue.

The relationship between self-perceived hearing ability and listening-related fatigue revealed that participants that reported more HD also tended to report more listening-related fatigue in their everyday lives. This finding is consistent with other studies (Hornsby & Kipp, 2016; Pang et al., 2019). Hornsby and Kipp (2016) found that the amount of listening-related fatigue a person felt was driven by the degree of HD they perceived rather than their actual amount of hearing loss. In contrast to the current study which utilized the AAPS, Hornsby and Kipp utilized the Hearing Handicap Inventory for the Elderly (Newman et al., 1990) to record the amount of HD participants experienced. Increased listening-related fatigue as a result of hearing loss or HD might be due to the increased cognitive demand required to understand speech in challenging listening environments. Given this idea, the cognitive subscale of the VFS-A may be useful for interpretation. In the current study, total fatigue scores were greater than any other domain, even the cognitive domain. Still, the cognitive domain scores were greater than the other subcategory scores. This is in agreement with results of Hornsby and Kipp (2016). Similar to the relationship described above, self-perceived hearing ability and listening-related fatigue specifically in the cognitive domain were significantly related. When participants reported more HD, they also reported more listening-related fatigue in the cognitive domain. These results suggest that individuals that discern more HD are likely to also struggle with listening-related fatigue. It may be beneficial to counsel patients that report HD on the listening-related fatigue they may also experience.

In addition to listening-related fatigue, the relationship between self-reported HD and listening effort on study tasks was evaluated. Pearson's correlational analysis revealed that participants perceived more HD also felt that they exerted more effort on the complex auditory tasks of this study. This suggests that individuals struggling more to hear and understand may feel that they are exerting more effort on complex auditory tasks that take place in noisy environments and engage auditory working memory. This is consistent with Mackersie and Cones (2011) who found that participants exerted a greater amount of effort when the listening task load became more difficult despite minimal changes in overall task performance. Mackersie and Cones utilized an objective measure of effort, recording psychophysiological measures (i.e., heart rate, skin conductance, skin temperature, and electromyographic activity) and a subjective measure, the NASA-TLX, to quantify effort. A strong correlation between the subjective and objective methods was not observed, however, all participants that rated their effort as greater by at least a factor of 4.5 also showed significant changes in skin conductance.

In the current study, participants felt that the pure-tone hearing test required the lowest amount of effort of all the tasks. The average participant effort score after the hearing test was 46, with higher scores indicating more effort exerted. After the speech-in-noise task, the average participant effort score was 75. After the auditory working memory task, participants on average scored effort at 73. Given that the standard hearing exam requires minimal effort, it might be useful to employ more rigorous testing methods in the clinic such as tests that engage auditory working memory and speech-in-noise tasks to more accurately replicate the difficult auditory situations that adults face in their everyday lives.

Conclusions

The results of this study suggest that adults that perceive more HD may also perceive greater listening-related fatigue. Adults with greater listening-related fatigue in this study felt that they exerted more effort and felt more frustration during complex auditory tasks. These tasks required auditory working memory and understanding speech-in-noise. Compared to these complex auditory tests that replicate everyday listening tasks, the standard hearing test was found to require very minimal effort. The hearing test provided no differentiation between listeners despite a variety of self-reported HD and listening-related fatigue scores. This study also emphasizes the usefulness of questionnaires in the clinic, as well as more rigorous auditory measures to ensure that individuals with normal pure-tone detection thresholds but HD are identified.

Future Directions

Future research should evaluate the relationships between EHF hearing, auditory working memory, self-perceived HD, listening-related fatigue, and effort, and speech-in-noise performance for individuals with more abnormal levels of HD as identified by the AAPS. Understanding how greater HD affects these auditory domains will allow for better identification and treatment for individuals with normal pure-tone detection thresholds and HD.

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