SPEECH IN NOISE ABILITY, OUTER HAIR CELL FUNCTION, AND WORKING MEMORY FOR TRAINED FLUTE PLAYERS

by

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April, 2015

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The process of auditory speech recognition requires verbal ability, working memory, recall, and adequate auditory abilities to recognize speech. There is a well-known positive effect of musical training and experience on verbal working memory and speech recognition in noise compared to those without formal musical training. This study was conducted to determine the relationships between outer hair cell function, speech in noise ability, and working memory for flute players (N=12) and non-musician controls (N=10). The secondary purpose of this study is to determine the differences between flute players and matched controls on these three variables. Test included pure tone audiometry, distortion product otoacoustic emissions (DPOAEs), working memory, and three speech in noise tests. Significant group differences were found between HINT thresholds using four talker babble in the Noise Front and Noise Right conditions. Non-musician controls were found to demonstrate a significant relationship between HINT 4T NF and bilateral high frequency DPOAEs. Flute players were found to demonstrate a significant negative relationship between working memory and outer hair cell function for the left ear, and a significant negative relationship between right high frequency DPOAEs and years of experience. Incidentally, the flute player group reported more perceived difficulty hearing speech in noise than the non-musician control group despite higher mean high frequency DPOAE response amplitudes than the controls. These data imply that another auditory or cognitive factor contributes to perceived difficulty recognizing speech in the presence of noise.

SPEECH IN NOISE ABILITY, OUTER HAIR CELL FUNCTION, AND WORKING MEMORY FOR TRAINED FLUTE PLAYERS

A Thesis

Presented To the Faculty of the Department of Communication Sciences and Disorders

East Carolina University

In Partial Fulfillment of the Requirements for the Degree

Master of Sciences in Communication Sciences and Disorders

by

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ACKNOWLEDGEMENTS

I would like to thank my advisor, Dr. Vermiglio, for assisting me in creating this research study and recruiting participants.

I would like to thank Sarah Faucette, Courtney Post, and Hannah Dorothy, audiology graduate students, for assisting me in preparing the protocol for the audiological tests.

I would also like to thank my husband, Charlie Caldwell for being a support throughout my studies in communication sciences and disorders, and for keeping me focused.

I would like to thank my parents for encouraging me to pursue my dreams and providing for me the upbringing and education to achieve my dreams.

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SIN	Speech in Noise	4
NF	Noise Front	8
KKS	King Kopetzky Syndrome	10
OAEs	Otoacoustic Emissions	10
TEOAE	Transient-Evoked Otoacoustic Emissions	11
DPOAE	Distortion Product Otoacoustic Emissions	12
QuickSIN	Quick Speech in Noise Test	15
HINT	Hearing in Noise Test	15
NR	Noise Right	16
NL	Noise Left	16
WJ III COG	Woodcock-Johnson III Test of Cognitive Abilities	16
ELU	Ease of Language Understanding	17
RAMBPHO	Rapidly, Automatically, and Multimodally Bound into a PHOnological representation	17
LTM	Long-Term Memory	19
WM	Working Memory	19
UMCIRB	University and Medical Center Institutional Review Board	31
SNR	Signal to Noise Ratio	34
HRTFs	Head Related Transfer Functions	35
NRev	Numbers Reversed	40
AWM	Auditory Working Memory	40

HINT 4T	HINT with Four Talker Babble..	45
HINT SS	HINT with Steady State Noise..	45
HF DPOAEs	High Frequency Distortion Product Otoacoustic Emissions	48

I. INTRODUCTION

SPEECH IN NOISE DEFINED

Imagine listening to someone talk in a quiet room. The speaker has no competing signal working against him, and the listener is able to focus his attention on the speaker's message. The listener is at an advantage in a quiet room because there is little competition for auditory attention. However, listeners are often in other environments, where a variety of competing auditory signals are present. These situations require auditory and cognitive skills to filter and discriminate the speech target from environmental noise and other competing signals. Cherry (1953) states that "we can listen to one speaker when another is speaking simultaneously; these are acts of recognition and discrimination" (p. 975). Speech recognition in noise research has been conducted over the past 60 years but has not always remained in the limelight (Darwin, 2009). Research on speech perception largely ignores the problem that "we listen to speech against a background of often intense, irrelevant sounds" (Darwin, 2009, p. 151).

Speech recognition in noise, according to Chandrasekaran and Kraus (2010), may be defined as the extraction of "key features in the signal while suppressing irrelevant details, temporarily storing this information while ignoring noise, processing a stream from a single source in the midst of numerous other sources (e.g. a speaker's voice), and using linguistic context to 'fill in' details lost in the noise" (p. 297). The listener attempting to recognize speech in the presence of background noise utilizes signal discrimination, working memory, and linguistic processing throughout the associational tracts in the cortex. Someone who has difficulty with extracting, suppressing, storing, processing from a single source, or filling in linguistic context may struggle in tasks requiring such skills.

Speech Recognition in Noise Ability

Nearly everyone who has ever had a hearing test is likely familiar with pure tone audiometry: the listener is instructed to respond when he hears tones. The audiologist varies the intensity of the presentation to determine the threshold at which the listener responds. Pure tone threshold testing provides information regarding hearing sensitivity across a range of frequencies, 250 to 8000 Hz. It is useful for determining hearing loss severity, the type, and shape of hearing loss (Rutka, 2010; Kramer, 2014). Type of hearing loss reflected in the audiogram is a gross representation of the location of loss within the "conductive and/or sensorineural parts of the auditory system" (Kramer, 2014, p. 148). The location or cause can be more clearly delineated with other audiological measures.

If people walked around responding to tones in quiet environments, pure tone threshold testing would likely provide a clear analysis of hearing sensitivity. Additionally, knowing that the hearing loss is conductive or sensorineural from pure tone audiometry provides insight into the function of the cochlea. This is valuable information, but does not connect to speech perception and recognition. Kramer (2014) noted that "a primary complaint for many people with hearing loss is that even though they may hear people talking, they have difficulty understanding what is being said, especially when there is background noise" (p. 212). In this respect, using a test specifically for speech recognition in noise may provide an appropriate measure of the functional impairment of hearing difficulties. An individual may have difficulty recognizing speech in the presence in noise and yet have a normal audiogram, which has been confirmed in numerous studies (Hinchcliffe, 1992; Zhao & Stephens, 2000; Middelweerd, Festen, & Plomp, 1990). Therefore, assessing an individual's ability to recognize speech in noise gives a more complete view of functional limitations than pure tone audiometry alone. In a world of health care management and insurance regulations, quantifying impairments with objective, measurable data is critical.

The Cocktail Party Problem

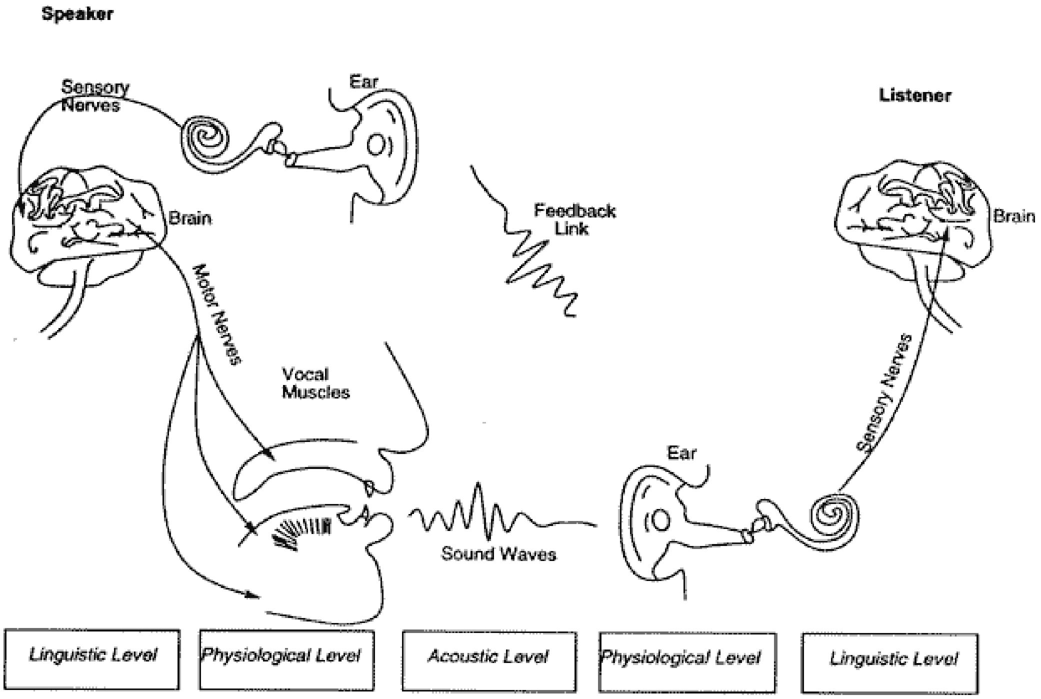
When an assessment is done to determine functional hearing abilities, it is important to consider a variety of communicative contexts. Noise is present in many of the communicative contexts people experience, and that noise may fluctuate, remain steady, and change in intensity or composition. An individual attempting to hear speech in a noisy environment utilizes extraction, discrimination, and recognition to hone in on the target speech signal amidst the noise. Cherry (1953) first called this situation the "cocktail party problem," which he defines as a difficulty in the ability to "Recognize what one person is saying when others are speaking at the same time."

In order for a message to be received by a listener, recognition and discrimination of speech from the background noise is the first step. In the Rabiner and Schafer (1978) model of speech encoding and decoding, the speaker forms a message, encodes it linguistically and physiologically, and it is passed to the listener acoustically. The listener's auditory system processes the acoustic signal at the physiological level, and the message is decoded at the linguistic level. The original model of speech encoding and decoding by Rabiner and Schafer (1978) is presented in Figure 1.

The competing noise in the cocktail party problem may cause a listener to change the acoustic situation in his favor, such as moving closer to the speaker, filling in the lost parts of the message with linguistic assumptions, and turning his head toward the speaker. Cherry (1953) proposes that a listener in such environments has an “instinctive action to turn one ear toward him” and goes on to explain that this turning may “increase the difference between the messages reaching the two ears.” The idea of binaural differences in speech perception breaks the notion that speech recognition in noise ability can be measured in only one noise condition or direction. An individual with a speech recognition in noise deficit may only notice it in certain situations, such as a loud party to his right and the desired speaker toward his left, and vice versa. Utilizing directional testing for speech in noise (SIN) assessments provides additional information for the plan of care and possible compensatory strategies needed to improve the ability to communicate in the proverbial cocktail party.

Figure 1

Speech Encoding and Decoding



Note: Rabiner & Schafer, 1978

A Brief History of Pure Tone Thresholds and SIN Testing

The pure tone audiogram is considered to be the “gold standard” in determining hearing loss (Sindhusake et al., 2001). Jones and Knudson (1924) invented an audiometer that generated pure tones, while Fletcher and Steinburg (1929) created an audiometer used for speech recognition in quiet with recorded digits. These audiometers have been the basis for evaluating the ears both separately and together (Wilson & McArdle, 2005). A seminal article on speech audiometry by Carhart (1951) has been the basis for describing hearing loss in terms of loss of acuity or deficiency in clarity of speech that is received. The clarity of the speech signal is the issue at hand when attempting to recognizing speech in noise for everyone, with or without a loss in measured acuity.

There are generally two types of speech recognition testing: speech in quiet and speech in noise. According to Wilson and McArdle (2005), a SIN task is only used by professional in specific situations where the ability to recognize speech in noise is the primary complaint. Several reasons are stated for the lack of clinical use of SIN tests, including the length of time to evaluate, clinical training focused on presenting words in quiet, and change that would be required in the field of audiology. An assessment must maintain internal validity in the sense that it appropriately measures what is sets out to measure. Asking the listener to repeat words in quiet evaluates that skill, and should not presume to indicate the ability to recognize speech in the presence of background noise, nor should it be assumed to predict the shape of the audiogram (Kramer, 2014).

The Picket Fence Effect

Miller and Licklider (1950) examined speech recognition in noise tasks and phonemic context. Research protocols included regularly spaced interruptions while a recorded list of words was played for the listener. Participants were able to recognize words when the interrupting noise was presented at a rate of 10 per second, with an accuracy rate of 75% of the test words. The authors conclude that with speech interruption rates at 10 to 15 per second, the listener perceives the speech as continuous an uninterrupted, similar to the visual perception of moving quickly past a landscape with a picket fence blocking it at regular intervals. When the authors varied the noise type, listeners reported that the words were easier to recognize with white noise rather than pure tone interruptions, although the measured score of recognized words did not vary. They found that a single glimpse per phoneme was sufficient for the listener to perceive the target word. The listener is able to decode the linguistic signal as long as a glimpse of each phoneme is available, much like the glimpse of the landscape between the pickets.

Middelweerd et al. (1990) studied steady state and fluctuating noise as the masking types in speech recognition in noise tasks. The patient group in the study consisted of 15 individuals who complained of diminishing speech intelligibility, which was defined as a declining ability to recognize speech. The control group consisted of 10 individuals with normal hearing. Participants underwent routine pure tone threshold testing as well as intelligibility in quiet testing, and reportedly demonstrated “virtually no hearing loss” and 90 to 100% intelligibility scores on monosyllabic words presented at 45 and 60 dB HL. Performance between groups was compared on speech recognition thresholds. In quiet conditions, the control group demonstrated a lower threshold (24.2 dBA) than the patient group (27.8 dBA). When examining performance in steady state noise, the average speech recognition threshold was lower (better) for the control group than the patient group, with signal-to-noise ratios of -5.7 and -4.7 dB respectively. In fluctuating noise, the difference between groups was larger. The fluctuating noise was delivered monaurally, and the signal to noise ratios were -12.6 dB for controls and -9.6 dB for patients. The difference of 3 dB between groups on fluctuating noise performance was noted to be statistically significant. The 1 dB difference on the steady state noise task compared to the 3 dB difference on the fluctuating noise task was reported to be statistically significant. The 3 dB difference in performance during fluctuating noise "implies speech intelligibility scores 36% than those of the control group" (p. 5). For those individuals complaining of difficulty recognizing speech in noise, a speech recognition in noise task is sensitive to those complaints, and a fluctuating masking noise may be more sensitive to "temporal resolution in hearing function" than steady-state noise. The authors inferred a temporal resolution problem for the patient group, which was not confirmed in the study. Speech recognition in fluctuating noise testing may reveal aspects of SIN ability that are not revealed with speech recognition in steady state noise.

Steady State Noise Studies

Testing with steady state noise as the masking condition was studied on a large scale by Vermiglio, Soli, Freed, and Fisher (2012). There were 215 participants in the final data set. Tests included pure tone audiometry, speech in quiet, and speech in steady state noise. A significant relationship was found between speech in quiet condition and pure tone thresholds, but no significant relationship was found between pure tone thresholds and the noise-front (NF) condition. This indicates that recognition of speech in quiet can be assumed on some level from the audiogram, but not the ability to recognize speech in steady state noise.

A recent study by Moore et al. (2014) was conducted with over 500,000 participants ages 40-69, to examine SIN ability and cognitive processing. Participants completed a computer-based test requiring them to enter monosyllabic single digits they hard while spectrally-shaped noise was simultaneously delivered. Participants also answered survey questions regarding hearing difficulties, otologic history, and difficulty recognizing speech in noise. In this study, more men reported hearing difficulties than women at all ages, but these subjective reports did not match the pattern of decline of pure tone averages or speech recognition thresholds. The authors give two possible explanations for the mismatch: the tests were insufficient to capture the hearing handicap, or people perceive their hearing ability to be worse than it actually is.

Cognition and hearing were also examined in the Moore et al. (2014) study using a battery of cognitive tests, including the fluid intelligence test, prospective memory, reaction time, and digit span. Comparisons across age groups indicated declines in verbal and non-verbal cognitive tasks with advancing age with a simple pattern of decline around age 60. The relationship between hearing and cognition in this study revealed a decline with age across the cognitive spectrum on speech recognition tasks. The authors conclude that "age-related changes in cognitive function are mediated by age-related changes in global sensory processing," i.e. hearing, vision, touch composite, and that poor cognitive function may play a minor role in reduced pure tone averages. The study used a digits recognition task for SIN testing rather than sentences or monosyllabic words, and did not test with any other types or directions of masking noise.

Normal Audiograms and SIN Deficits

King (1954) used the term “psychogenic deafness” to describe the difficulty an individual claims to have when attempting to understand speech in noise. He proposed multiple reasons for those deficits, including personality, anxiety, lack of confidence, manifestation of hysteria, and malingering. He presented six cases, and in only 2 of those cases did he document organic defect; the others had normal audiograms. Hinchcliffe (1992) studied individuals with normal audiograms and complaints of difficulty recognizing speech in noise. He called this disorder King-Kopetzky Syndrome (KKS). By the standards used to determine hearing loss severity, a normal audiogram should theoretically reflect normal hearing sensitivity (Rutka, 2010). Because a pure tone audiogram does not necessarily represent a functional measure of SIN ability, and does not significantly correlate with SIN ability (Middelweerd et al., 1990; Vermiglio et al. 2012), a normal audiogram provides no information regarding SIN ability and little information is provided regarding the etiology. Researchers have attempted to determine the etiology of KKS. Suggested etiologies have included auditory or language-based dysfunctions (Lagace, Jutras, & Gagne, 2010), psychological issues (King, 1954), auditory neuropathy (Rance, 2007), and cochlear damage (Zhao & Stephens, 2006).

Otoacoustic Emissions

Otoacoustic emissions (OAEs) are the sounds generated by the motion of the outer hair cells in the cochlea. Outer hair cells are embedded in the tectorial membrane, causing the basilar and tectorial membranes to be pulled together and pushed apart. Inner hair cells move in response to the action of the basilar and tectorial membranes, and connect to the afferent pathways responsible for transducing sensory information to the auditory nerve (Kramer, 2014).

It is the movement of these membranes that enhances frequency sensitivity and amplifies the wave of motion. The motion of the outer hair cells has been called the “cochlear amplifier” (Davis, 1983). In other words, the motion of the outer hair cells allows the cochlea to respond to very low level sounds.

OAEs were first discovered by Kemp (1978), who found a slowly decaying response to auditory stimulation. The responses were present in ears that were considered normal but absent in those with cochlear deafness. OAEs are a reflection of the functionality of the outer hair cells. Bright and Kastner-Wells (1994) measured transient-evoked otoacoustic emissions (TEOAEs) for two groups of individuals with normal audiograms. The control group had no exposure to high levels of noise, and the experimental group had at least some exposure to high levels of noise. Findings indicated a reduction in high-frequency TEOAE amplitudes for the experimental group. In the study, OAEs were found to be a reflection of the functionality of the outer hair cells and were damaged for those with high levels of noise exposure.

Zhao and Stephens (2006) examined the relationship between cochlear damage and difficulty recognizing speech in the presence of noise for individuals with KKS compared to normal hearing controls. The control group inclusion criteria were no recent hearing difficulty, normal otoscopy and pure tone thresholds, and normal middle ear function. The inclusion criteria for the KKS group included seeking help for hearing difficulties including problems recognizing speech in the presence of noise, audiometrically normal hearing, no obvious causes, and no signs of conductive pathology. Individuals in both groups had clinically normal hearing sensitivity, defined by thresholds at or below 30 dB HL across frequencies ranging from 0.25 to 8 kHz, and thresholds at or below 20 dB HL from 0.5 to 4 kHz in the poorer ear. The KKS group was found to have a low occurrence of TEOAEs (77%) and significantly lower global mean levels of distortion product otoacoustic emission (DPOAEs) than the control group ($p < 0.05$). The authors reported decreased response amplitudes of DPOAEs over a limited frequency range for individuals with KKS. Individuals with speech recognition in noise complaints presented with DPOAEs with lower amplitudes than those without speech recognition in noise complaints. From this, one can infer that outer hair cells are important for the perception of speech in the presence of noise.

WORKING MEMORY

Working memory has been defined as a limited capacity system, which temporarily stores and maintains information, providing an interface between perception, long term memory, and action (Baddeley, 2003; Baddeley & Hitch, 1974; Miller, Galanter, & Pribram, 1960). The theoretical model explaining how working memory functions is based on the central executive system in combination with two storage systems (Baddeley, 2003). The central executive system involves problem solving, planning, and reasoning (Cowan, 2010). An assessment of working memory provides the clinician insight into the effect it may have on mental tasks such as language comprehension, arithmetic problem solving, and planning, such as maximizing the efficiency of one's chores or errands to run.

The two storage systems involved in working memory are the phonological loop and visuospatial sketchpad. The phonological loop briefly stores memory traces, both consciously and unconsciously (Baddeley, 2003). Serial recall has been used to assess the phonological loop: as the number of items in the series increases, the memory of the first item(s) fades (Conrad & Hull, 1964). The visuospatial sketchpad utilizes color, location, shape, and other pertinent features to retain items (Baddeley, 2003). Retention of stimuli depends on the recall limit as well as the individual's ability to chunk. Chunking is the grouping of "constituent features," can be used for a limited period of time, and is "a process that demands attention" (Baddeley, 2003, p. 833). Cowan (2010) defines chunking as meaningful items grouped together. Working memory tasks that require the listener to categorize stimuli to recall as many as possible require chunking skills. Serial presentation as well as chunking tasks are utilized in the process of cognitive encoding, or putting information into working memory, measured by the recall limit (Cowan, 2010). Individuals retain between three and five chunks of stimuli when they are unaware of when the list of stimuli will end, provided the items can be grouped (Cowan, 2001).

Research on Working Memory

Researchers have found two effects which confound the measurement of working memory: phonological similarity, and the word-length effect. As the word increases in length from one to five syllables, immediate memory span declines, and sound similarities assist with memory for unrelated stimuli (Baller & Baddeley, 1984). Phonological chunking takes place when there are similarities in sounds between stimuli. These similarities provide an element of linguistic encoding that increases recall limit capacity (Baddeley, 2003). Cowan (2010) noted that working memory ability can vary widely “depending on what processes can be applied to the task,” such as rehearsing covertly, chunking multiple words, sequencing visual pathways, and depend on whether those processing strategies are prevented or controlled.

Multiple modalities of chunking interfere with assessments of working memory. Moreover, two modalities have been shown to improve cognitive processing (Cowan & Morey, 2007). Modalities of processing may include similarities in word sound (e.g. cat, car, cave), semantic relationships (e.g. types of animals), lexical hierarchies (e.g. animal, horse, calf), and visual similarities (e.g. clock, pie, plate). Tests of working memory must mask stimuli so they are mixed and meaningless in order to confine the assessment to central working memory (Cowan, 2010). Assessment of the phonological loop requires an auditory presentation of stimuli, also essential to confine the task to working memory. Targeting the singular ability of recall capacity with unrelated, meaningless information presented verbally limits the listener’s working memory capacity to central memory stores and central executive functions, while simultaneously drawing upon the phonological loop and visuospatial sketchpad to drive cognitive encoding.

Working memory assessments typically require the individual to change the stimuli in some way prior to repeating them. SIN tests require an individual to repeat stimuli such as words and sentences. The interplay of cognitive skills such as working memory with a word or sentence repetition task may be pose a problem when one intends to study the auditory ability to recognize speech in noise: working memory capacity is limited (Cowan, 2001). Additionally, because chunking skills assist with recall of related items, the visuospatial sketchpad in conjunction with the phonological loop limit word and sentence recall when the listener is unaware of when the stimulus will end. An individual struggling with a speech in noise task may therefore have a cognitive component in his reduced ability to recognize speech in noise. It would be prudent then, to consider the relationship of working memory and speech in noise for individuals with normal audiograms and SIN complaints.

SIN and Working Memory

Studies have shown that musicians have better speech in noise abilities than non-musician controls (Musacchia et al., 2007; Patel, 2011; Parbery-Clark et al., 2009; Wong et al., 2007). A significant relationship was found between SIN ability and working memory for both musicians and non-musicians (Parbery-Clark et al., 2009). The Parbery-Clark et al. (2009) study examined the effect of musical training on SIN ability and working memory. Tests included a frequency discrimination task (termed "auditory acuity"), working memory assessments, and two SIN tests: the Quick Speech in Noise Test (QuickSIN; Killion et al., 2004) and the Hearing in Noise Test (HINT; Nilsson, Soli & Sullivan, 1994; Vermiglio, 2008). The standard version of the HINT was administered, which uses speech-shaped steady state noise and three directional conditions: Noise Front (NF), Noise Right (NR), and Noise Left (NL). The QuickSIN uses a four-talker babble, which is a fluctuating noise. Working memory was assessed using the Numbers Reversed and Auditory Working Memory subtests from the Woodcock-Johnson III Test of Cognitive Abilities (*WJ III COG*; Woodcock et al., 2001). The association between QuickSIN performance and working memory was statistically significant ($r = -0.578$, $p < 0.001$). The relationship between the HINT-NF and working memory was statistically significant but weaker ($r = -0.369$, $p = 0.041$). The authors proposed that these two SIN tests may not be examining the same skills, and found no statistically significant relationship between performance on the QuickSIN and the HINT in any of the conditions (NF, NR, or NL). Because musicians also demonstrated better SIN performance than non-musicians, the authors attributed the musicians' better SIN ability to greater working memory performance as the "driving force" (Parbery-Clark et al., 2009).

The musician enhancement for SIN was the main basis of the Parbery-Clark et al. (2009) study. When comparing the group of musicians to non-musicians, the authors found no significant difference between groups on the HINT NR and HINT NL. There were statistically significant differences between groups on the QuickSIN ($p = 0.004$) and HINT NF ($p = 0.008$), and the musicians had lower thresholds for the measured signal to noise ratio than non-musicians. The musician group also had significantly better frequency discrimination thresholds ($p = 0.001$) than non-musicians. Frequency discrimination was measured by presenting two tones and asking the participant to determine which tone was higher in frequency. The standard tone of 1000 Hz was used, as well as a variable tone between 1002 Hz and 1600 Hz. A comparison between frequency discrimination thresholds and the SIN tests in the study revealed a stronger relationship with the QuickSIN (r = 0.511, p = 0.003) than the HINT NF (r = -0.155, p = 0.404) for both participant groups.

When examining training, the authors found that years of practice for the musician group was positively associated with working memory scores (r = 0.614, p < 0.001) and negatively with QuickSIN performance (r = -0.580, p = 0.001). The idea that musical training can improve performance on cognitive measures such as working memory hinges on the idea that musicians have better working memory than non-musicians. In this study, the musician group outperformed the non-musician group on the working memory measures, however with a relatively small number of participants (16 musicians, 15 non-musicians), larger scale studies are needed before determining that this advantage in cognitive skills perpetuates across all groups of individuals with formal musical training.

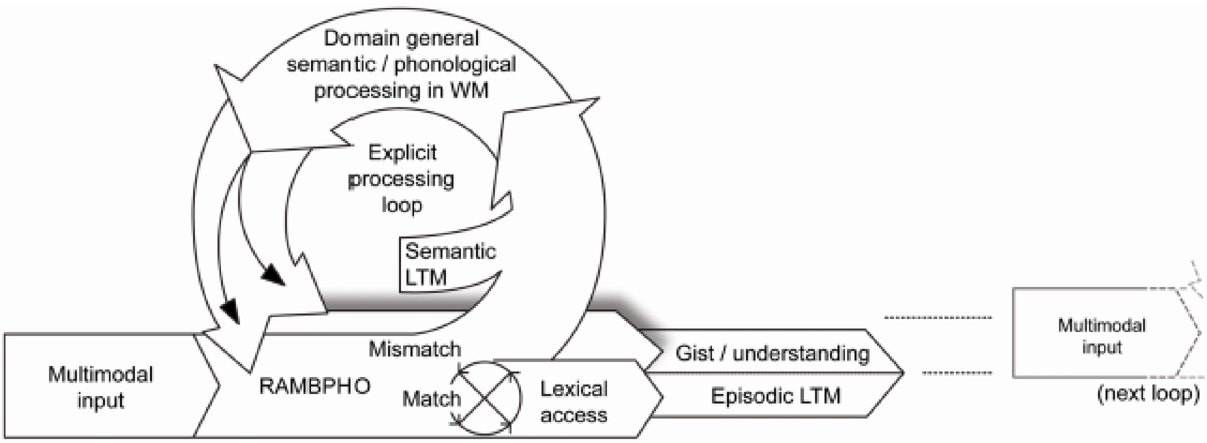
The ELU Model: A Theoretical Model to Understand Cognitive Demands during SIN Tasks

The Ease of Language Understanding (ELU) model is multimodal and accounts for listening conditions, sufficient phonological attributes, mental lexicon, and lexical access, modulated by working memory. In this model, working memory supports listening when listening conditions are substandard. The interaction with long term memory takes place as the neural networks access lexical knowledge. ELU provides a model to explain the interface of these systems (Rönnberg et al., 2013). The visual representation of this model is shown in figure 2.

Rönnberg et al. (2013) describe a process they call “RAMBPHO,” which is defined as “Rapidly, Automatically, and Multimodally Bound into a PHOnological representation.” The sequence that initiates at RAMBPHO in the ELU model lines up well with the description of the phonological loop and visuospatial sketchpad, the two storage systems in the working memory model previously described (Baddeley, 2003; Baddeley & Hitch, 1974; Miller, Galanter & Pribram, 1960). Rönnberg et al. (2013) describe it as an episodic buffer for the purposes of feed-forward into lexical activation and access. The cycle can be delayed or discontinued if RAMBPHO information "cannot be immediately related to phonological representations in semantic long term memory or is not precise enough to match them unambiguously." At this point, the authors state that working memory compensates for the mismatch by engaging the processes previously described as necessary for SIN ability: extraction, attention, storing information, and inhibiting irrelevant information. The authors propose that the incoming speech signal will cause processes such as working memory, long-term memory, and lexical access to fluctuate during a conversation. Demands on cognitive processes during highly loaded tasks, which engage working memory capacity, may provide an explanation for the significant association between performance on working memory measures and SIN tests.

Figure 2

The Ease of Language Understanding (ELU) Model



Note: The ELU model describes the interface of working memory when the listener is faced with multimodal input. RAMBPHO = “Rapidly, Automatically, and Multimodally Bound into a PHOnological representation.” LTM = long-term memory. WM = working memory. From Rönnberg et al., 2013.

Limitations of the Parbery-Clark Study

The musicians included in the Parbery-Clark et al. (2009) study played violin or piano, and these results may not carry over to other instrument groups. Since high levels of sound exposure can negatively affect hearing sensitivity, it is important to consider the levels of sound exposure for various musicians. In the Parbery-Clark study, no other instrument groups were included and the data were not separated by instrument groups. A group of instruments not represented in the study may reveal patterns in test performance that may contradict the previous results.

Based on the findings of Kastner-Wells (1994) regarding the impact of exposure to high levels of sound, it is possible that individuals with high levels of sound exposure may have reduced high frequency DPOAE amplitudes. Reduced DPOAE amplitudes at higher frequencies have been attributed to outer hair cell damage (Littman, Magruder, & Strother, 1998). Additionally, individuals with KKS were found to have significantly lower global mean levels of DPOAEs than controls (Zhao & Stephens, 2006). Therefore, outer hair cell function appears to be related to SIN ability (Stephens, Zhao & Kennedy, 2003). The Parbery-Clark study did not include an assessment of outer hair cell function.

The results of the Parbery-Clark study indicated a stronger relationship between performance on the QuickSIN and working memory than the HINT NF and working memory across participant groups. The authors attributed the difference in these relationships to the length of the sentences (N. Kraus, personal communication, April 2014). During the QuickSIN protocol, the participant responds while listening to continuous babble noise. During the HINT, the participant responds while listening to silence. These testing conditions may change the demands on cognitive processing and compete with the phonological loop and visuospatial sketchpad the listener must use in order to encode the stimuli in working memory.

The HINT in the study was the standard version, which used steady state noise. The QuickSIN uses four talker babble. It has been shown that steady state noise and fluctuating noise in SIN tests produce different results (Middelweerd et al., 1990). If the tests are presumed to be testing different skills, but are both considered SIN tests, the clinician selecting tests for a battery of assessments must be aware of the significant association with working memory on the QuickSIN and the less significant association with the HINT NF.

Musicians are potentially at-risk for high levels of sound exposure. Johnson, Sherman, Aldridge, and Lorraine (1985) investigated the effects of instrument type and position in the orchestra seating arrangement on hearing sensitivity for a wide range of frequencies, 0.25 to 20 kHz. The most notable finding is that participants demonstrated no significant hearing sensitivity differences when comparing different types of instrumentalists on pure tone threshold testing.

Schmidt et al. (2011) conducted a study examining the sound exposure of symphony orchestra musicians with a total of 1154 sound level measurements throughout the orchestra at the level of the musicians' ears. Results indicated binaural differences in sound exposure, which varied by instrument type. The highest levels of sound exposure were recorded in the brass section. The authors noted binaural differences in all sections, with the greatest difference between ears for brass players as well, ranging from 4.6 to 10 dB differences. Across instrument sections, flute player sound exposure was 95.4 dBA (left) and 97.6 dBA (right). Percussionists demonstrated the highest sound level exposure at 115 dBA.

Russo et al. (2013) tested a group of ballet orchestra musicians to determine the relationship between high levels of noise exposure and measurable hearing loss. The highest levels of sound were measured in the brasses, then woodwinds, percussion, and bass sections. Lowest levels of noise were measured in the strings sections. Measurements of hearing sensitivity of each musician were reported, with the worst pure tone thresholds demonstrated by bassists and percussionists at 25 dB HL, with the most significant loss at 6000 Hz. This level of hearing sensitivity is considered within normal limits for adults. The authors stated this measured hearing level of 25 dB HL bordered on a clinically significant loss, despite the fact that none of the measured hearing sensitivity thresholds would be considered outside the clinically accepted norm.

Rodrigues et al. (2014) examined the noise exposure of symphony orchestra musicians across various repertoire types. The authors reported peak sound levels at 135 dBC in the brass and percussion sections. They did not conduct pure tone threshold tests to determine if there was an effect of noise exposure on hearing sensitivity. Study protocol measured sound exposure during group rehearsals. Individuals in the symphony orchestra taught lessons and completed individual practice sessions when they were not rehearsing with the large ensemble, and these activities were not monitored for sound exposure. Because the authors were unable to account for an individual's dosage of sound throughout all possible situations, the authors suggested measuring all musical activities including individual practice and teaching sessions as a better determinate of the risk of hearing loss for each individual.

Orchestral musicians have been found to have normal hearing sensitivity with pure tone threshold testing (Johnson et al., 1985; Russo et al., 2013). Unfortunately, speech recognition in noise ability was not evaluated in these studies, nor were the participants asked if they perceived any difficulty recognizing speech in the presence of background noise. The risk of hearing loss for musicians is high, due to exposure to sound levels from their own instrument as well as the noise of others simultaneously (Rodrigues et al., 2014). Clinical hearing loss is typically determined by pure tone threshold testing, however, and assessment of speech recognition in noise ability may provide details regarding the function of the auditory system beyond the audiology booth. SIN testing could provide measurable, objective data regarding the functional impairments for those who have exposure to high levels of sound, such as musicians. Exposure to high levels of sound is strongly associated with outer hair cell damage. The function of the outer hair cells may be related to SIN ability. Therefore, a measurement of cochlear function with DPOAEs may provide information regarding minor changes in the cochlea.

Flute Players and Noise Exposure

Flute players experience exposure to sound levels ranging from 85 to 111 dBA, and those who play piccolo may experience sound levels ranging from 95 to 112 dBA (Thom et al., 2005). In a ballet orchestra, flute players experienced exposure up to 87 dBA (Russo et al., 2013). In a symphony orchestra, flute players may experience sound exposure at to 91.9 dBA (Rodrigues et al. 2014) and 97.6 dBA (Schmidt et al., 2011). Pianists such as those included in the Parbery-Clark et al. (2009) study have been found to have sound exposure levels from 92 to 95 dBA; violinists have sound exposure levels from 84 to 103 dBA (Thom et al., 2005; Schmidt et al., 2011).

According to the Occupational Safety and Health Administration (OSHA, 2008), an individual should not be exposed to consistent sound levels at 105 dBA for more than one hour per day. The practice time during which Rodrigues et al. (2014) were unable to measure sound exposure levels exceeded two hours per day. Maximum exposure time to sound levels above 110 dBA should not exceed 30 minutes (OSHA, 2008). The college level training requirements experienced by the author were three hours of individual practice per day, not including rehearsals with ensembles, performances, or musical training courses. Self-perception of sound level dosage is not reliable (Rodrigues et al., 2014). Therefore musicians may not have the ability to monitor sound dosage without additional objective instruments.

The use of hearing protection is warranted by OSHA (2008) for situations in which the worker is exposed to high levels of sound. Using traditional foam ear plugs or any other type of hearing protection is commonly used as a tactic when musicians are training fingering patterns for difficult passages. However, the recommendation for tone studies, or training tone quality on the instrument, is nearly impossible to do with hearing protection in place. Tonal training is essential to an instrumentalist's formal music training (Moyse, 1973). As a member of the woodwind family, the flute player must be able to extract and identify each of the sounds of the other instruments and do so "without hesitation, while listening to a chord emitted by all of the members of this great family joined together" (Moyse, 1973, p. 7). Moyse goes on to emphasize the importance of tone development and the player's ability to notice intricacies in tone and vibrato, and states "for an artist the most precious of gifts certainly is the gift of observation (p. 17). Many practice sessions and rehearsals may be completed with little to no hearing protection as an effort to pursue appropriate tonal development for the instrument and chosen emotive goal. Monitoring noise exposure via a dosimeter, previously suggested by Rodrigues et al. (2014) may be a prudent application to reduce the risk of hearing loss and avoid permanent cochlear damage for flute players as well as other groups of instrumentalists.

Benefits of Musical Training

Researchers have asserted that musicians have special training compared to non-musicians (Chandrasekaran & Kraus, 2010; Parbery-Clark et al., 2012; Trainor & Corrigall, 2010). In a review of a broad range of studies on musician enhancement for specific auditory skills, Chandrasekaran and Kraus (2010) found that musicians performed better on the following skills than non-musicians:

- Source segregation
- Top-down expectation

- Rapid spectro-temporal processing
- Auditory attention
- Auditory working memory
- Sequencing skills
- Noise exclusion

Musicians have an advantage over non-musicians in frequency discrimination. Research has shown that frequency discrimination is useful in "object formulation" and increase the ability to "tag a speaker's voice" during speech recognition in noise tasks (Chandrasekaran & Kraus, 2010). Pitch is the perceptual correlate of frequency, and musicians are trained on pitch discrimination from a very early age. Parbery-Clark et al. (2009) used a frequency discrimination to determine this difference between groups, as previously described. The authors conclude that musical training and better pitch discrimination may transfer into and enhance nonmusical domains, such as speech perception.

Musicians and SIN Ability

Musician and non-musician comparison studies provide unique insight into possible contributors for enhanced SIN ability. According to Chandrasekaran and Kraus (2010), "Musicians, as a consequence of training that requires consistent practice, online manipulation, and monitoring of their instrument, are experts in extracting relevant signals from the complex soundscape (e.g. the sound of their own instrument in an orchestra)." Extraction of a signal from competing noise is an essential skill for speech recognition in noise tasks. Musicians practice the skill of extraction during every practice session, rehearsal, and performance. Parbery-Clark et al. (2012) states that musicians have more finely tuned auditory systems. Measuring the auditory system via specific measures such as SIN tests and DPOAEs may provide insight into the enhancement of the auditory system in musicians.

PROBLEM STATEMENT

The audiogram provides valuable information about hearing sensitivity and further testing that may be warranted. Pure tone thresholds, however, cannot be used to predict the ability recognize speech in noise (Middelweerd et al., 1990; Vermiglio et al. 2012). A normal audiogram does not ensure normal functional auditory abilities, and individuals with normal audiograms may complain of difficulty recognizing speech in the presence of background noise. One of the etiologies for a SIN deficit is damage to the cochlea (Zhao & Stephens, 2006; Vermiglio, 2007). Cochlear damage may be measured using otoacoustic emissions, and is an indicator of outer hair cell function (Stephens, Zhao, & Kennedy, 2003). High frequency otoacoustic emissions are reduced in amplitude for individuals with exposure to high levels of noise (Bright & Kastner-Wells, 1994), and musicians are a group that may be at risk for high levels of noise exposure (Schmidt et al., 2011; Rodrigues et al., 2014). Musicians have been shown to have better SIN ability than non-musicians (Musacchia et al., 2007; Patel, 2011; Parbery-Clark et al., 2009; Wong et al., 2007). Additionally, Parbery-Clark et al. (2009) found that SIN ability was correlated with working memory performance for both musicians and non-musicians. Musicians had lower (better) SIN ability and high working memory scores than non-musicians. The Parbery-Clark et al. (2009) study utilized the QuickSIN with its four talker babble, and the HINT standard version, which is available commercially with steady state noise. The previous study did not include a group of instrumentalists with regular sound level exposures above 110 dBA, such as flute players. The primary purpose of this study is to determine the relationships between SIN ability, outer hair cell function, and working memory performance. The secondary purpose of this study is to determine group differences between flute players and non-musician controls on these variables.

RESEARCH QUESTIONS

This research study is designed to study differences between groups, with a systematic inquiry to understand the auditory and working memory profile of each participant. The auditory profile includes pure tone audiometry, otoacoustic emissions, and speech-in-noise testing. The working memory profile examines short-term memory and manipulation of speech stimuli including numbers and objects. The three major variables of interest are speech in noise, working memory, and outer hair cell function. In order to determine relationships between these variables, analyses and pairwise comparisons will be conducted in addition to other statistical analyses to be further explored. In order to account for uncontrolled variables, a questionnaire will be employed to examine participants' hearing experiences and complaints, including history of noise exposure, reported difficulty of hearing speech in the presence of background noise, use of hearing protection, and years of flute training. The specific research questions to be explored in this study are as follows:

1. What are the differences between flute players and non-musician controls on SIN ability, working memory, and DPOAEs?
2. What is the relationship between SIN ability and high frequency DPOAEs for both groups?
3. What is the relationship between years of experience, working memory, and high frequency DPOAEs for flute players?
4. What is the relationship between self-perception of difficulty recognizing speech in noise and DPOAEs?

II. METHODS

PARTICIPANT GROUPS

There were two groups of participants in this study: a flute player group and a non-musician control group. The flute player group consisted of adults age 18-30, mean age 20.8, (standard deviation 3.19) with a minimum of seven years of musical training on the flute beginning at or before age 12 and consistent practice for the past three years. Consistent practice is defined as a minimum of two practice or performance sessions per week. The non-musician control group consisted of adults age 18-30, mean age of 20.5 (standard deviation 0.85), with no more than three years of formal music instruction, and no musical instruction in the past three years. For the flute player group, the mean number of hours practiced per week was 13.7 (standard deviation 7.83), and average number of years of training was 10.1 (standard deviation 3.48). The mean pure tone average (at 500, 1000, 2000 Hz) was -0.33 dB HL for controls and 0.14 dB HL for flute players. All participants had normal pure tone thresholds between -10 and 25 dB HL across tested frequencies from 250 to 8000 Hz. All of the flute player participants have been or currently are majoring in music.

TESTING PROCEDURES

In conjunction with the speech perception lab, procedures for testing were created and modified by the speech perception senior lab staff. The procedures were written into a manual for the lab and executed as prescribed for each participant. Each participant was allowed sufficient time to read the Informed Consent to Participate in Research, which is included in Appendix B. A questionnaire was used to obtain information regarding hearing experiences, hearing complaints, musical training, and use of hearing protection. The questionnaire was also used to determine eligibility for inclusion in study groups. The questionnaire was approved by the University and Medical Center Institutional Review Board (UMCIRB) at East Carolina University, as noted in the approval letter in Appendix A. The participant questionnaire is presented in Appendix C.

Otoscopy was conducted first for the participants. The external ear canal was checked to determine it if was in healthy condition and not occluded by cerumen. The tympanic membrane was checked to determine if it was intact and reflected the cone of light. Full occlusion of the canal was an exclusion factor, and partial occlusion was permissible unless pure tone thresholds exceeded the normal range (-10 to 25 dB HL).

Tympanometry and acoustic reflex thresholds were conducted using the GSI Tympstar. All participants had normal ear canal volume and peak pressure. Norms were taken from Wiley (1987). Acoustic reflex thresholds were conducted at 500, 1000, and 2000 Hz both ipsilaterally and contralaterally, which were not an exclusion factor for the present study.

Pure tone thresholds were measured via air and bone conduction through the GSI 61 audiometer using pulse-tones and the Hughson-Weslake procedure, consistent with the guidelines published by the American Speech-Language and Hearing Association (ASHA; 1978).

DPOAEs

Distortion product otoacoustic emissions (DPOAEs) were performed to evaluate cochlear function. The testing parameters are those described in Vermiglio (2007), who found a significant relationship between composite HINT scores and high-frequency DPOAEs. Six points per octave for a total of 25 frequencies (450 – 9000 Hz) per trial were tested. The presentation levels of the test tones were L1 = 65 dB SPL and L2 = 55 dB SPL. Frequencies for F1 and F2 are listed in table 1.

The DPOAE response criteria for the present study was any DPOAE amplitude that was 6 dB above the noise measured in the ear canal. The actual stimulus presentation was subtracted from the target stimulus presentation of 65 or 55 dB SPL. In cases where the stimulus presentation difference was 6 dB or more, those responses were deemed invalid and eliminated from further calculations. Response amplitudes for valid stimulus presentations for frequencies of 2000 Hz to 9000 Hz were averaged to determine the participant’s high frequency mean DPOAE amplitude for right and left ears. The average high frequency DPOAE amplitude represents a measure of the outer hair cell function. Higher response amplitudes indicate better outer hair cell function, and lower response amplitudes indicate worse outer hair cell function.

Table 1

DPOAE test Frequencies

Frequency 1 (Hz)	Frequency 2 (Hz)
454.83	547.75
513.52	616.22
577.10	689.58
645.56	772.72
723.81	870.53
811.85	978.13
914.55	1095.5
1027.03	1227.55
1149.30	1379.16
1291.13	1550.33
1447.63	1741.07
1628.58	1951.36
1824.21	2191.01
2049.18	2459.99
2298.60	2758.32
2582.26	3100.66
2900.15	3477.24
3252.27	3902.73
3653.31	4382.01
4098.35	4919.98
4602.09	5521.53
5164.51	6196.44
5795.41	6954.49
6504.55	7805.46
7301.72	8764.02

QuickSIN

The Quick Speech in Noise Test (QuickSIN; Killion et al., 2004) provides a brief measure of an individual's ability to recognize and repeat sentence in the presence of noise. The standard noise in the QuickSIN is four talker babble, which is a recording of four people talking simultaneously. This test was conducted with simultaneous presentation of babble and sentences on a single track. The sentence stimuli are spoken by a female. The participant was instructed to repeat each sentence that the woman says. The participants were instructed that the background talkers will gradually become louder, making it difficult to understand the woman's voice. Participants were encouraged to guess and repeat as much of the sentence as possible. The starting signal to noise ratio (SNR) is 25 dB SNR, which decreases by 5 dB for each sentence throughout six sentences, for a SNR delivery of 25, 20, 15, 10, 5, and 0 dB SNR. Scoring was conducted by tabulating the number of keywords correctly stated by the participant in each sentence. There are five keywords in each sentence and a maximum score of 30 for each six sentence list. The SNR loss was calculated by subtracting the number of keywords repeated correctly from 25.5. For the purposes of this study, the selection of possible lists was limited to those with equal difficulty with a mean of 12.2 dBA and deviations <1 dBA from the mean: lists 1, 2, 6, 8, 10, 11 (McArdle & Wilson, 2007). Performance across four randomly selected lists of sentences was averaged to find the mean SNR loss and reported in dB. The sentence lists were randomized. The QuickSIN materials were presented from a PC and routed to a GSI 61 audiometer to supra-aural TDH earphones (model 296D200-2). The QuickSIN calibration tone was used to set the input level on the audiometer. Both channels of the audiometer were set at 70 dB HL, and the signal was routed to both ears.

HINT

The Hearing in Noise Test (HINT) (Nilsson, Soli & Sullivan, 1994; Vermiglio, 2008) uses an adaptive protocol to test speech recognition in noise abilities under various noise conditions and noise directions simulated under headphones using KEMAR head-related transfer functions (HRTFs). The following conditions were tested: Noise Left (NL), Noise Front (NF), and Noise Right (NR), as illustrated in figure 3. The head related transfer functions (HRTFs) simulates a sound field environment where the speakers are located 1 meter from the center of the participant's head. This includes the head-shadow effect, which is illustrated in figure 4. Table 2 lists the headphone routing with speech, noise, unshadowed noise, and unshadowed noise. Calibration procedures for the HINT were performed during the set-up of the speech perception lab at ECU and are included in Appendix E.

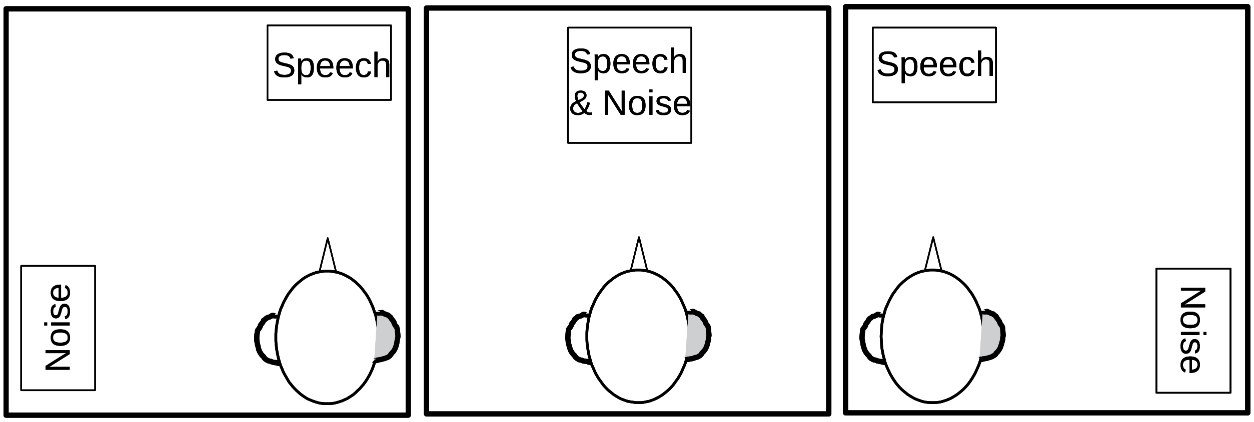
The noise conditions used for the HINT in this study are four talker babble and steady state noise with three directions: NF, NR, and NL. In the HINT, the talker is a male. The adaptive protocol utilizes a step size of 4 dB for the first four sentences and a step size of 2 dB for the remaining sentences. The level of the noise was fixed at 65 dBA. The starting SNR was 0 dB SNR on NF and -5 dB SNR on NR and NL. As the test continues, the level of speech varies based on the participant's ability to correctly repeat all of the words in the sentence. The HINT threshold is defined as the threshold at which the participant repeats at least 50% of the sentences correctly. The HINT conditions for this study included four talker babble and steady state noise. The four talker babble was taken from the same babble used to create the masking noise of the QuickSIN, with sound files from Auditec. Each participant had an administration of a practice test in quiet to familiarize him with the test. The composite score for each background noise condition was calculated by the following formula:

$$[2(NF) + NR + NL] / 4.$$

The HINT composite index represents the participant's global ability to recognize speech in the presence of noise.

Figure 3

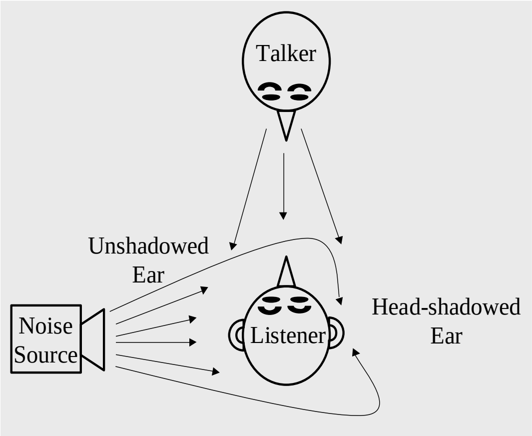
Three HINT Conditions Presented via Simulated Sound Field



Note: The noise conditions represented in the figure from left to right are NL, NF, and NR (Vermiglio, 2007).

Figure 4

Illustration of the Sound Field Environment Simulated Under Headphones



Note: The figure shows the HINT in the Noise Left condition along with the head-shadow effect (Vermiglio, 2007).

Table 2

Headphone Routing and HINT Conditions using Headphones with HRTF

HINT Condition	**Signal to Left Headphone**	**Signal to Right Headphone**
Quiet	Speech at 0 degrees	Speech
Noise Front (NF)	Speech and Noise at 0 degrees	Speech and Noise
Noise Right (NR)	Speech and Head-shadowed Noise at 90 degrees	Speech and Unshadowed Noise at 90 degrees
Noise Left (NL)	Speech and Unshadowed Noise at 270 degrees	Speech and Head-shadowed Noise

Working Memory

In order to assess working memory, two subtests from the Woodcock-Johnson III Test of Cognitive Abilities (WJ III COG; Woodcock, McCrew & Mather, 2001) were administered: Numbers Reversed (NRev) and Auditory Working Memory (AWM). The NRev subtest uses a series of single digit numbers at a rate of one per second and increases the length of the series to a maximum of eight numbers in a series. The participant must recall the series of numbers in reverse order from their original presentation. For example, in the stimulus “2 – 5” the participant must respond with “5 – 2.” If needed, participants were cued to state the numbers in reverse order.

The AWM subtest states a collection of things and numbers, e.g. “5 – apple.” The participant is asked to name the things first in the order they were presented, then the numbers in the order they were presented. In the example above, the participant would respond “apple – 5.” A more difficult stimulus, such as “coat – 5 – 9 - juice” the participant would respond “coat – juice – 5 – 9.” A cue was allowed to remind the participant to state the things first, then the numbers. Total working memory scores were calculated by combining the performance on the NRev and AWM subtests, consistent with the testing procedures by Woodcock et al. (2001) and the same procedures used by Parbery-Clark et al. (2009).

At the conclusion of all testing, participants were given a summary of their test results on pure tone audiometry (air and bone conduction) and HINT scores in quiet as well as steady state noise. Norms for the HINT using steady state noise were taken from Vermiglio (2008). The participant handout including information on hearing conservation is available in Appendix F.

STATISTICAL ANALYSIS

Test results were entered into a database using Microsoft Excel. Statistical analysis consisted of a mixture of descriptive statistics, data visualizations, and bivariate analysis. Pearson correlation statistics were used to determine the differences between groups on the associations among years of experience, DPOAEs, working memory, and performance on SIN tests. Independent samples t-tests were used to determine if the difference between group means on each of the testing parameters. A Fisher r-to-z transformation was used to determine if there was a significant difference between within-group correlation values. Software used to calculate these values was made available by Preacher (2002). JMP ® Pro 11 statistical software was used for all calculations and graphic display of the results of the study. P-values were calculated and evaluated against a level of significance of 0.05 for all statistical tests.

III. RESULTS

Table 3

Group Means on High Frequency DPOAEs

Evaluation	**Mean (SD)**		**Significant Difference Between Groups?**
	Controls n=10	**Flute Players n=12**	
Left Average High-Frequency DPOAE Amplitude (2-9 kHz)	1.63 (5.56)	3.95 (4.04)	No (p=0.14)
Right Average High-Frequency DPOAE Amplitude (2-9 kHz)	1.68 (4.79)	3.90 (4.91)	No (p=0.15)

Table 4

Group Means on Pure Tone Averages

Evaluation	**Mean (SD)**		**Significant Difference Between Groups?**
	Controls n=10	**Flute Players n=12**	
L Pure Tone Average for 500, 1000, 2000 Hz (dB HL)	-0.33 (5.38)	0.14 (3.92)	No (p=0.40)
R Pure Tone Average for 500, 1000, 2000 Hz (dB HL)	1.833 (4.94)	2.08 (4.27)	No (p=0.45)
L Pure Tone Average for 3, 4, 6 kHz (dB HL)	3.998 (5.73)	2.50 (4.63)	No (p=0.26)
R Pure Tone Average for 3, 4, 6 kHz (dB HL)	3.833 (4.72)	2.22 (3.85)	No (p=0.19)

Table 5

Group Means on Working Memory Measures

Evaluation	**Mean (SD)**		**Significant Difference Between Groups?**
	Controls n=10	**Flute Players n=12**	
Numbers Reversed Subtest	16 (4)	17 (5)	No (p=0.36)
Auditory Working Memory Subtest	32 (4)	32 (4)	No (p=0.45)
Working Memory Total	48.10 (7.54)	48.58 (7.55)	No (p=0.44)

Table 6

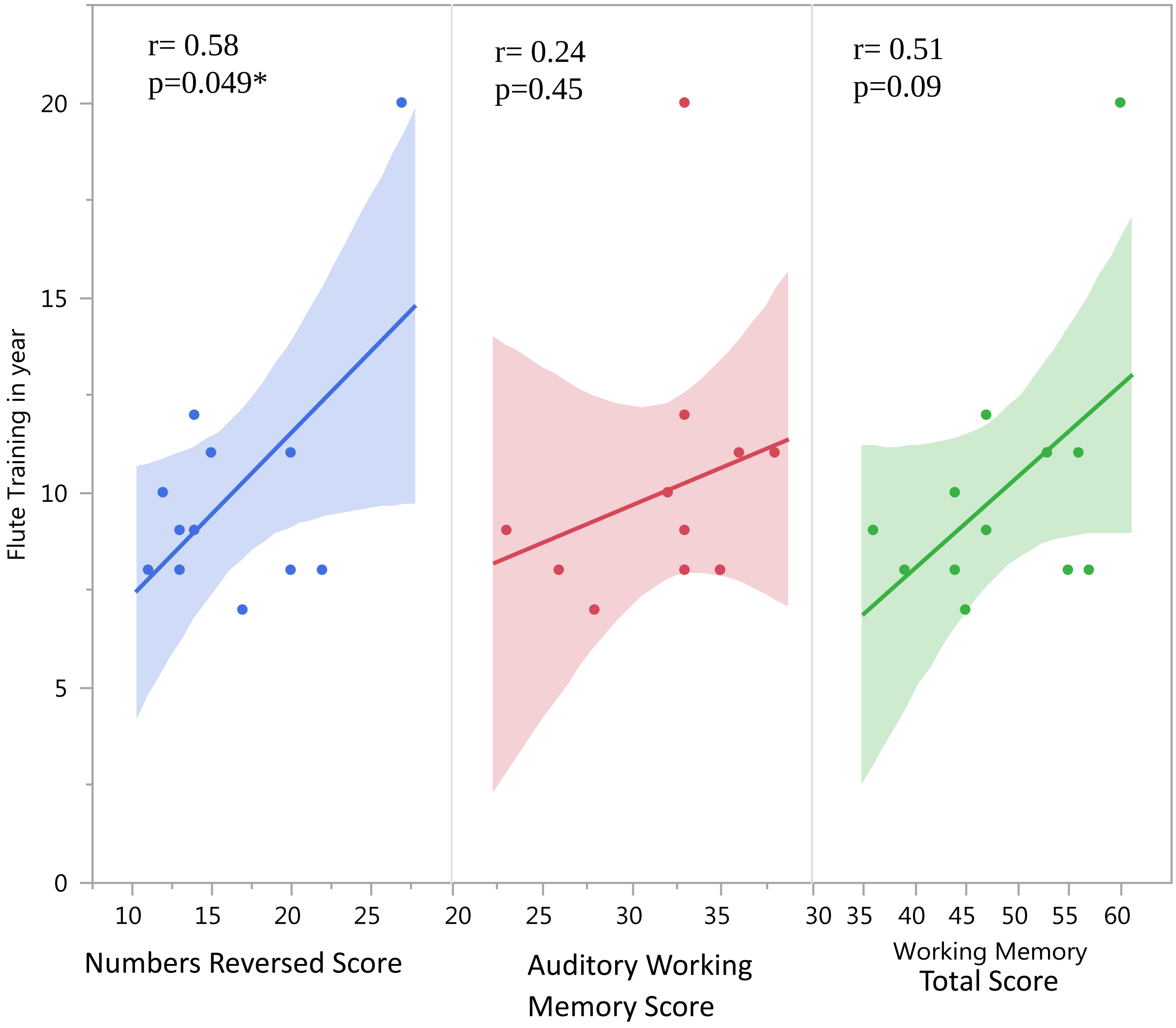
Group Means on HINT and QuickSIN

Evaluation	**Mean (SD)**		**Significant Difference Between Groups?**
	Controls n=10	**Flute Players n=12**	
HINT Quiet (dBA)	23.25 (3.69)	24.36 (2.54)	No (p=0.21)
HINT 4T NF (dB SNR)	***-2.92 (0.96)***	***-1.88 (1.50)***	***Yes (p=0.03)***
HINT 4T NR (dB SNR)	***-11.31 (0.94)***	***-10.14 (1.67)***	***Yes (p=0.02)***
HINT 4T NL (dB SNR)	-10.45 (1.66)	-9.96 (2.13)	No (p=0.27)
HINT 4T Composite (dB SNR)	***-6.90 (0.65)***	***-5.97 (1.53)***	***Yes (p=0.04)***
HINT SS NF (dB SNR)	-2.11 (0.90)	-2.03 (1.09)	No (p=0.42)
HINT SS NR (dB SNR)	-8.90 (1.32)	-8.16 (1.46)	No (p=0.11)
HINT SS NL (dB SNR)	-8.99 (1.14)	-8.83 (1.86)	No (p=0.40)
HINT SS Composite (dB SNR)	-5.53 (0.83)	-5.26 (1.08)	No (p=0.26)
QuickSIN SNR Loss	1.13 (1.40)	0.75 (0.83)	No (p=0.23)

Note: The bolded lines indicate Lines of data highlighted indicate the tests on which there were significant differences between groups. HINT 4T = HINT with four talker babble. HINT SS = HINT with steady state noise. NF = Noise Front. NR = Noise Right. NL = Noise Left. SNR = Signal to Noise Ratio.

Figure 5

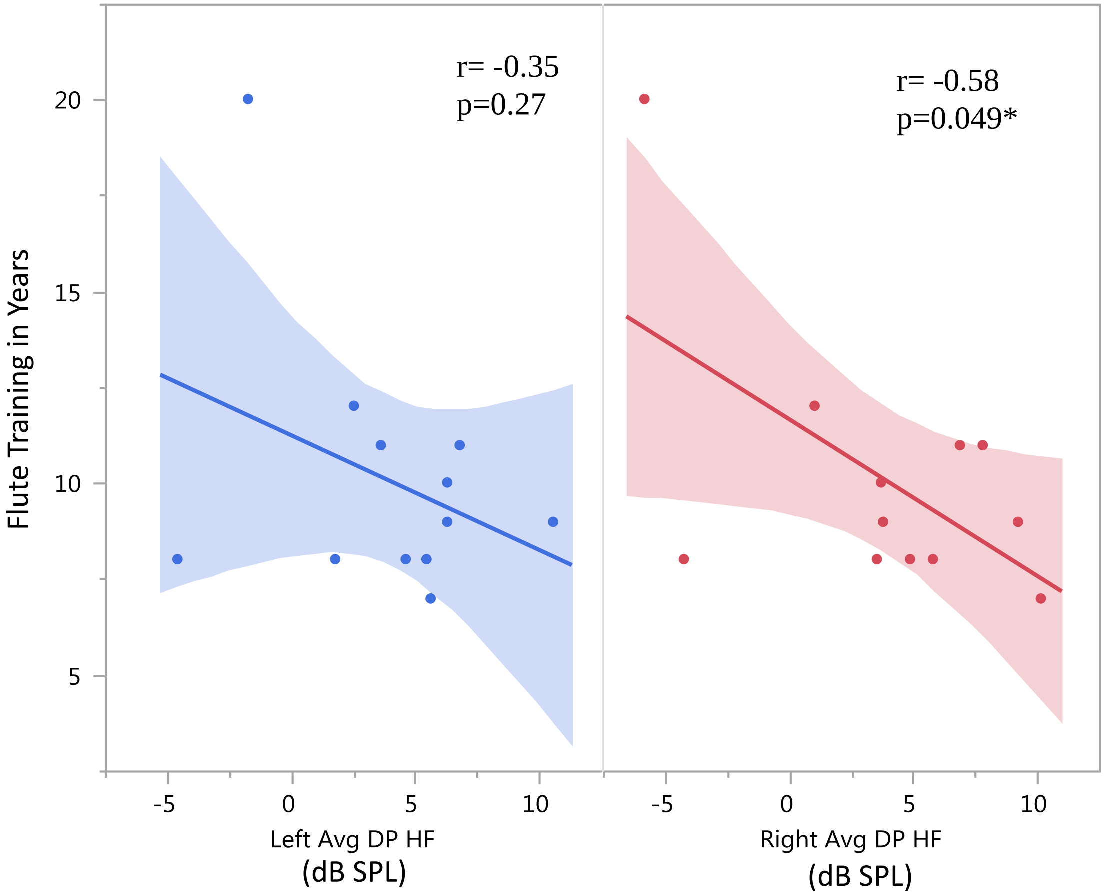
Working Memory vs. Years of Training for the Flute Player Group



Note: Working Memory is the total of the performance on the subtests included in the study: Numbers Reversed and Auditory Working Memory. A higher score on all measures indicates better performance. The correlation coefficient is indicated by r. The asterisk (*) indicates which relationship is statistically significant at a confidence level of $p < 0.05$.

Figure 6

High Frequency DPOAEs vs. Years of Training for the Flute Player Group



Note: Higher DPOAE response amplitudes represent better outer hair cell function. The asterisk (*) indicates which relationship is statistically significant at a confidence level of $p < 0.05$.

Table 7

Left and Right High Frequency DPOAEs and SIN Complaints

Group	**Left Average HF DPOAEs (dB SPL)**	**Right Average HF DPOAEs (dB SPL)**	**Difficulty hearing speech in noise?**
C1	-13.112	-8.459	no
C2	0.038	-3.411	no
C3	0.836	0.903	no
C4	1.688	1.7613	no
C5	3.323	4.633	no
C6	3.437	8.533	no
C7	3.818	5.055	no
C8	3.988	1.847	no
C9	***5.605***	***4.751***	***yes***
C10	***6.697***	***1.146***	***yes***
F1	-4.552	-4.251	no
F2	***-1.69***	***-5.798***	***yes***
F3	***1.774***	***3.542***	***yes***
F4	2.531	1.066	no
F5	3.602	6.928	no
F6	***4.611***	***4.845***	***yes***
F7	***5.486***	***5.782***	***yes***
F8	***5.609***	***10.161***	***yes***
F9	***6.274***	***3.785***	***yes***
F10	***6.334***	***3.708***	***yes***
F11	***6.836***	***7.797***	***yes***
F12	***10.535***	***9.245***	***yes***

Note: These data are for individual participants. The groups are abbreviated by C (controls) and F (flute players). Lines with bold font emphasize the “yes” response to the question asking the participant if he has difficulty hearing speech in a noisy environment. HF DPOAEs = High Frequency Distortion Product Otoacoustic Emissions.

Table 8

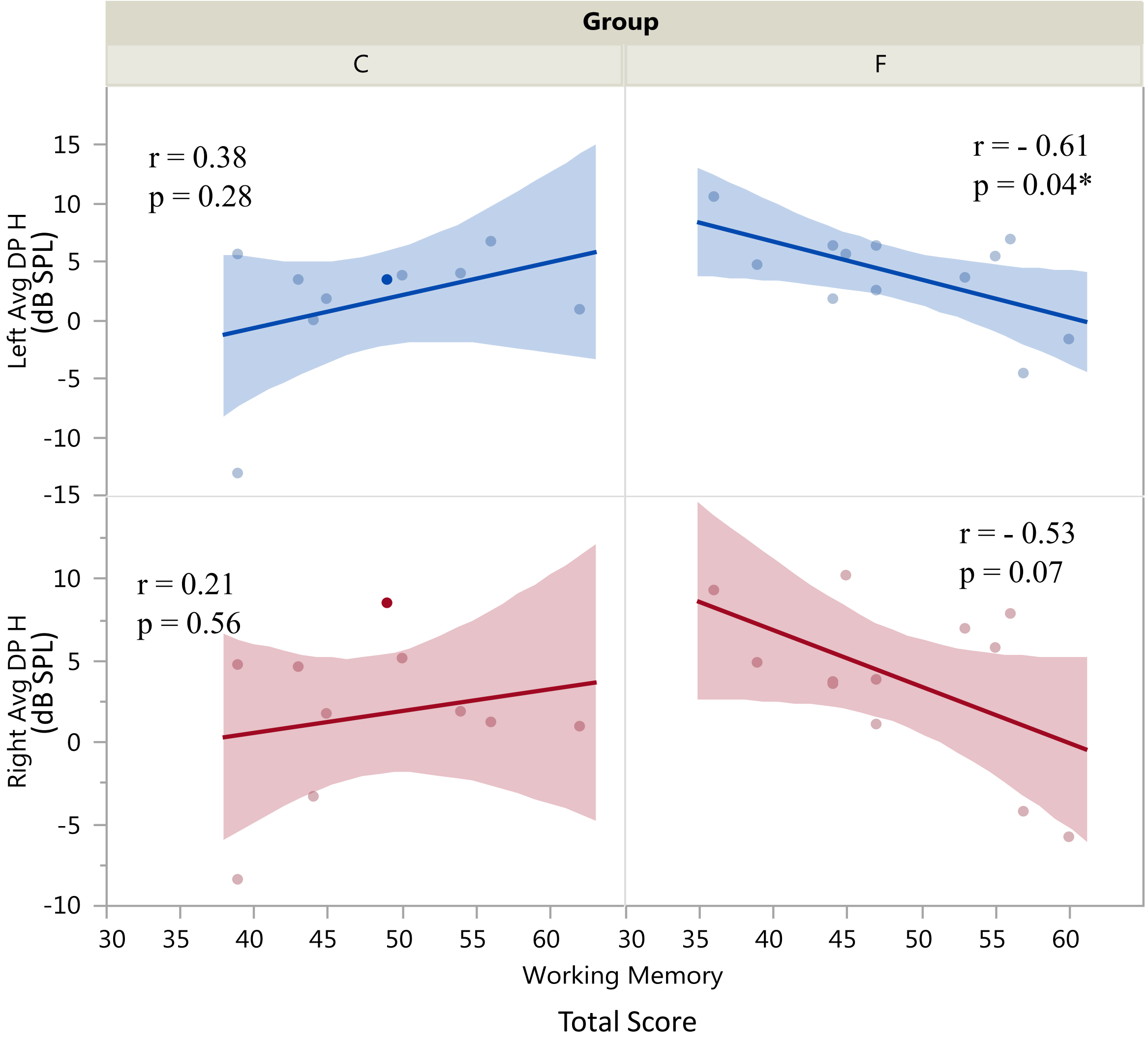
Mean Response Amplitudes of High Frequency DPOAEs

Group	**Left Average HF DPOAEs**	**Right Average HF DPOAEs**
Controls answering “no”	0.50	1.36
Controls answering “yes”	6.15	2.95
Flute players answering “no”	0.53	1.25
Flute players answering “yes”	5.09	4.79

Note: Both participant groups are separated into subgroups of those who perceive difficulty recognizing speech in a noisy environment and those who do not.

Figure 7

Correlation between Working Memory and HF DPOAEs



Note: The groups are abbreviated by C (controls) and F (flute players). The asterisk (*) indicates which relationship is statistically significant at a confidence level of $p < 0.05$.

Table 9

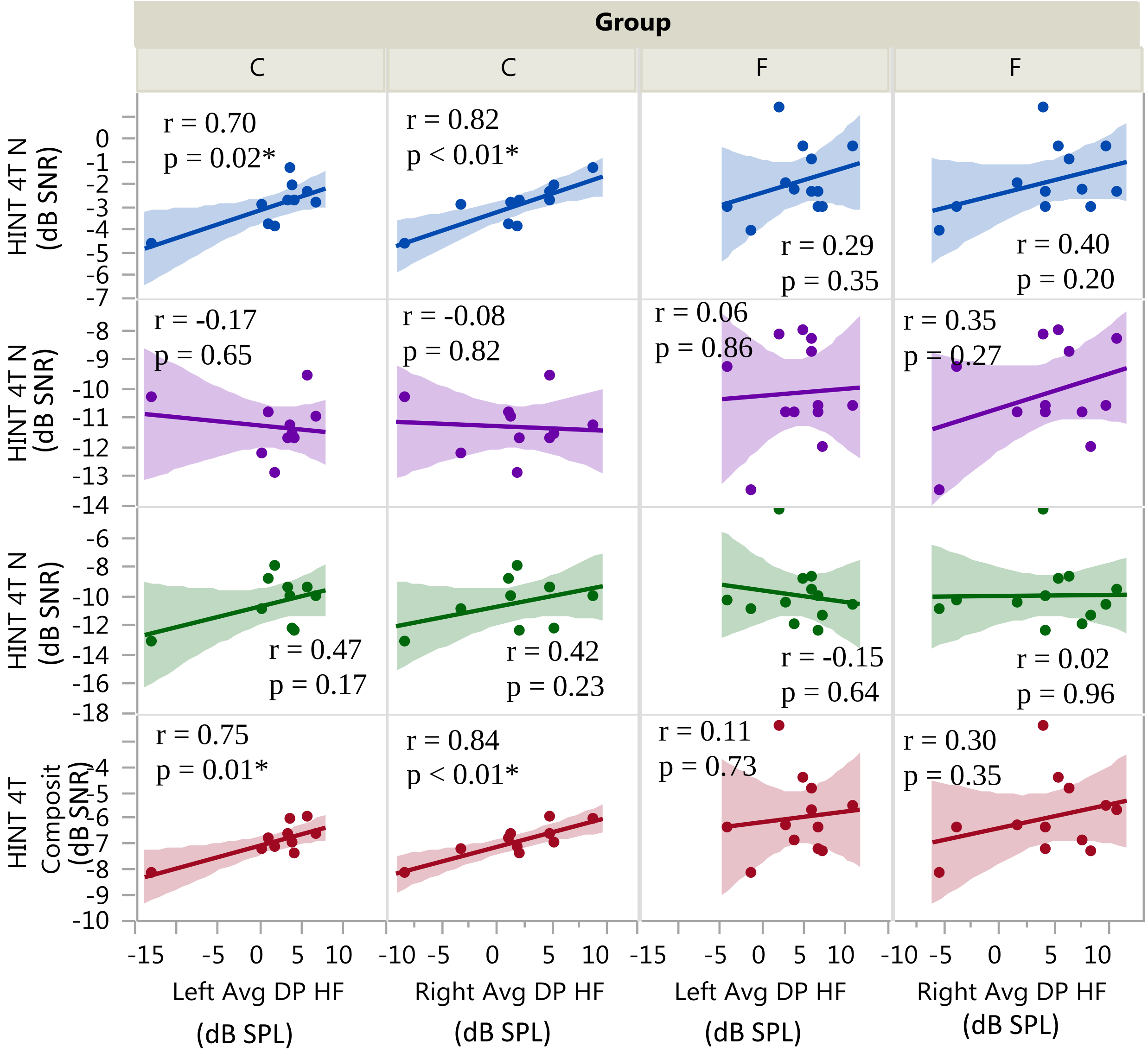
Relationships between SIN performance and HF DPOAEs, Divided by Ear and Group.

Measure	**Controls** correlation (p)		**Flute Players** correlation (p)	
	Left HF DPOAEs (dB SPL)	*Right HF DPOAEs (dB SPL)*	*Left HF DPOAEs (dB SPL)*	*Right HF DPOAEs (dB SPL)*
HINT 4T NF (dB SNR)	***0.70*** ***(p=0.02)***	***0.82*** ***(p<0.01)***	0.29 (p=0.35)	0.40 (p=0.20)
HINT 4T NR (dB SNR)	-0.17 (p=0.65)	-0.08 (p=0.82)	0.06 (p=0.86)	0.35 (p=0.27)
HINT 4T NL (dB SNR)	0.47 (p=0.17)	0.42 (p=0.23)	-0.15 (p=0.64)	0.02 (p=0.96)
HINT 4T Composite Scores (dB SNR)	***0.75*** ***(p=0.01)***	***0.84*** ***(p<0.01)***	0.11 (p=0.73)	0.30 (p=0.35)
HINT SS NF (dB SNR)	0.44 (p=0.20)	0.59 (p=0.07)	0.33 (p=0.29)	0.45 (p=0.14)
HINT SS NR (dB SNR)	-0.07 (p=0.84)	0.12 (p=0.74)	0.36 (p=0.25)	0.32 (p=0.31)
HINT SS NL (dB SNR)	0.28 (p=0.43)	0.32 (p=0.37)	0.08 (p=0.81)	-0.05 (p=0.86)
HINT SS Composite Scores (dB SNR)	0.30 (p=0.39)	0.48 (p=0.16)	0.32 (p=0.30)	0.32 (p=0.32)
QuickSIN SNR Loss	0.39 (p=0.27)	0.62 (p=0.06)	0.17 (p=0.60)	0.02 (p=0.95)
Right HF DPOAEs (dB SPL)	***0.81*** ***(p<0.01)***	n/a	***0.86*** ***(p<0.001)***	n/a

Note: The table shows the correlation coefficient (r) and p values between the various speech in noise tests and left/right high frequency DPOAEs. NR = Noise Right; NL = Noise Left; NF = Noise Front; 4T = Four Talker Babble; SS = Steady State Noise; HF DPOAEs = High Frequency Distortion Product Otoacoustic Emissions. Lines with bold font emphasize relationships which are statistically significant at a confidence level of $p < 0.05$.

Figure 8

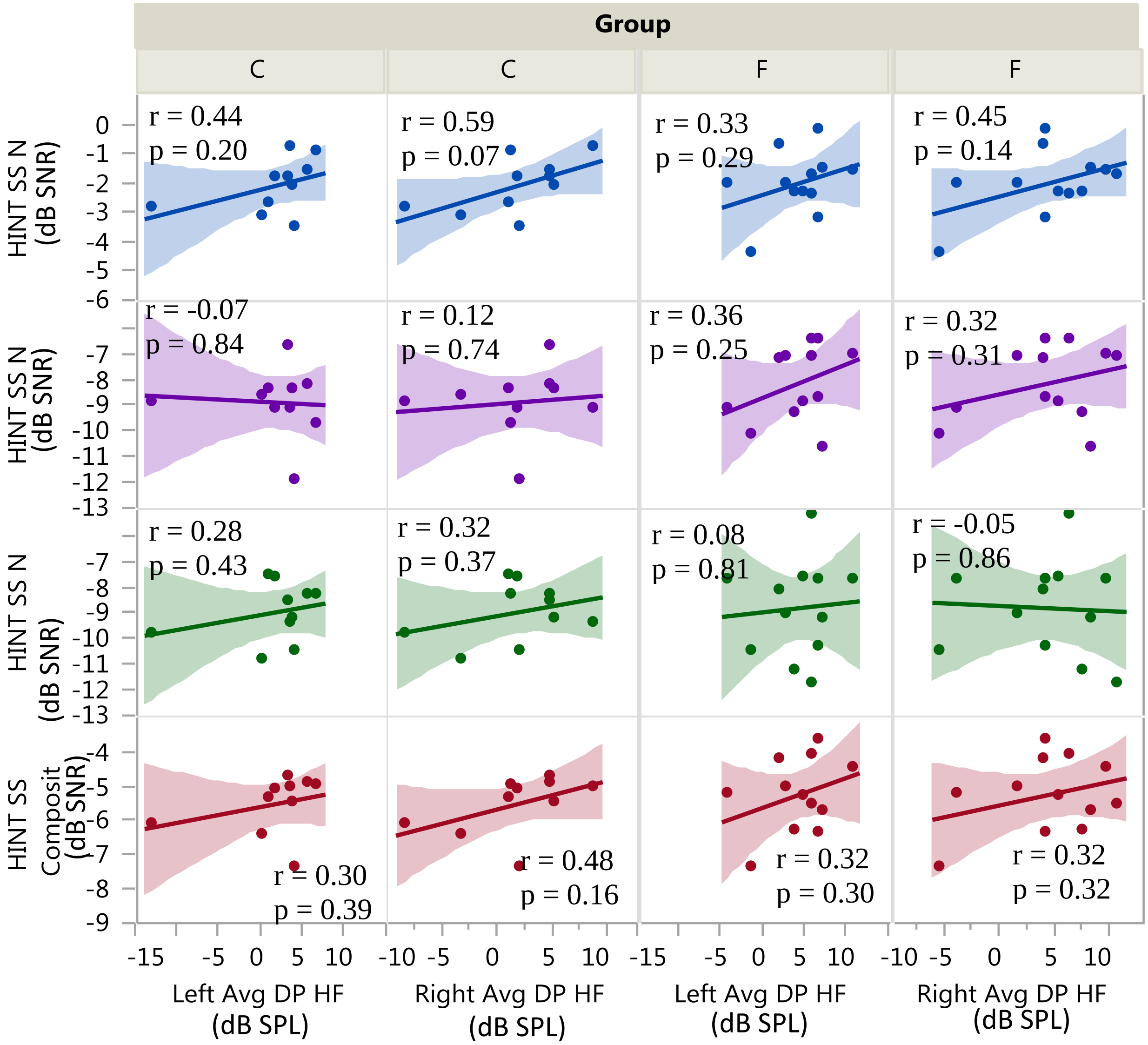
The Relationship between HINT with Four Talker Babble and Left/Right HF DPOAEs



Note: The groups are abbreviated by C (controls) and F (flute players). The correlation coefficient is indicated by r. NR = Noise Right; NL = Noise Left; NF = Noise Front; 4T = Four Talker Babble; HF DPOAEs = High Frequency Distortion Product Otoacoustic Emissions. The asterisk (*) indicates relationships that are statistically significant at a confidence level of $p < 0.05$.

Figure 9

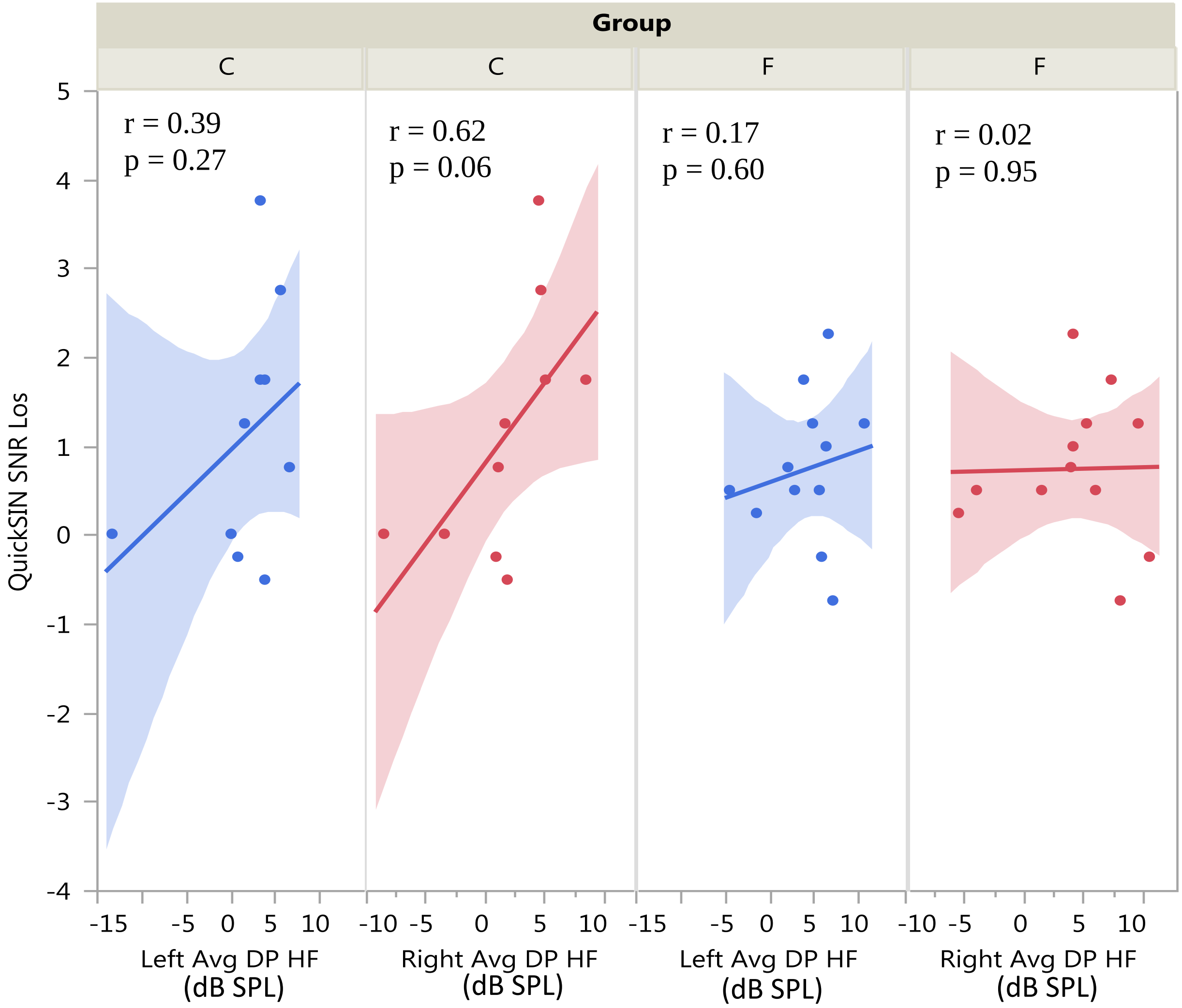
The Relationship between HINT with Steady State Noise and Left/Right HF DPOAEs



Note: The groups are abbreviated by C (controls) and F (flute players). The correlation coefficient is indicated by r. NR = Noise Right; NL = Noise Left; NF = Noise Front; SS = Steady State Noise; HF DPOAEs = High Frequency Distortion Product Otoacoustic Emissions. The asterisk (*) indicates relationships that are statistically significant at a level of confidence of $p < 0.05$.

Figure 10

The Relationship between QuickSIN SNR Loss and HF DPOAEs



Note: The groups are abbreviated by C (controls) and F (flute players). The correlation coefficient is indicated by r. HF DPOAEs = High Frequency Distortion Product Otoacoustic Emissions. The asterisk (*) indicates relationships that are statistically significant at a level of confidence of $p < 0.05$.

Table 10

Differences between Groups on Relationships with Working Memory, SIN, and HF DPOAEs

Association	**Correlation (r) values** *Controls (n=10)*	 *Flute Players (n=12)*	**Is the difference between (r) values significant?**
Working Memory and Left HF DPOAEs (dB SPL)	0.38	-0.61	***Yes*** ***z=2.21, p=0.01***
Working Memory and Right HF DPOAEs (dB SPL)	0.21	-0.53	No z=1.59, p=0.06
QuickSIN SNR Loss and Left HF DPOAEs (dB SPL)	0.39	0.17	No z=0.48, p=0.32
QuickSIN SNR Loss and Right HF DPOAEs (dB SPL)	0.62	0.02	No z=1.40, p=0.08
HINT 4T Composite Scores (dB SNR) and Left HF DPOAEs (dB SPL)	0.75	0.11	***Yes*** ***z=1.71, p=0.04***
HINT 4T Composite Scores (dB SNR) and Right HF DPOAEs (dB SPL)	0.84	0.30	***Yes*** ***z=1.81, p=0.04***
HINT SS Composite Scores (dB SNR) and Left HF DPOAEs (dB SPL)	0.30	0.32	No z=-0.04, p=0.48
HINT SS Composite Scores (dB SNR) and Right HF DPOAEs (dB SPL)	0.48	0.32	No z=0.38, p=0.35

The table shows the correlation coefficient (r) and p values between the various speech in noise tests, working memory performance, and left/right high frequency DPOAEs. NR = Noise Right; NL = Noise Left; NF = Noise Front; 4T = Four Talker Babble; SS = Steady State Noise; HF DPOAEs = High Frequency Distortion Product Otoacoustic Emissions. Lines with bold font emphasize relationships which are statistically significant at a confidence level of $p < 0.05$.

IV. DISCUSSION

SIN Ability

Significant differences between flute players and non-musicians across various measures were only found for the HINT four talker babble NF (p = 0.03), NR (p = 0.02), and composite scores (p = 0.04), as shown in table 10. While there were very few significant differences found, the control group performed better than the flute players on the HINT 4T across all noise directions, with lower threshold scores. For the HINT Noise Front condition, the difference between group means was 1.04, and the controls had the better score (-2.92 dB SNR). For the HINT Noise Right condition, the difference between group means was 1.17 dB, and the control group had a better mean score (-11.31 dB SNR). The difference in the composite score between groups was 0.93 dB. The controls performed significantly better than flute players on the HINT using four talker babble. Research has shown that fluctuating noise as the masking type may reveal aspects of SIN ability that are not apparent in steady state noise (Middelweerd et al., 1990). The mean performance by groups on the HINT using steady state noise, was much closer, was not significantly different between groups. The differences between groups were also much smaller, with differences of 0.08 on NF, 0.74 on NR, and composite score difference of 0.27. The control group had lower thresholds on the HINT SS than the flute player group.

There was no significant difference between groups for the QuickSIN (p = 0.23) despite lower SNR loss by the flute player group. There were significant differences between groups with better performance by the control group on two of the HINT 4T noise directions: NF (p = 0.03) and NR (p = 0.02). The Parbery-Clark et al. (2009) study found that the musician group performed better on the QuickSIN and the HINT SS than the non-musician group. In the present study, results indicate a contrast in group performance: the flute player group had worse

SIN ability than the control group on the HINT 4T and HINT SS, but better performance than the control group on the QuickSIN. The contrastive performance differences on the QuickSIN and HINT 4T and HINT SS found in the present study indicate that the two speech in noise tests may in fact be testing different skills, as was suggested by Parbery-Clark et al. (2009).

Outer Hair Cell Function

Mean high frequency DPOAE response amplitudes did not differ significantly between groups, although the lack of significance may be attributed to the low number of participants. The mean left and right high-frequency DPOAE response amplitudes were 1.63 and 1.68 dB SPL for the controls; 3.95 and 3.90 dB SPL for flute players, respectively. The controls had lower response amplitudes than the flute players despite the lack of statistical significance between groups. Expanding the present study to at least 20 participants in each group may provide statistically significant differences between groups if the pattern of higher DPOAE response amplitudes for the flute player group versus controls continues in a similar way.

The Fisher r-to-z transformation was used to determine if there is a significant difference in the relationship of two independent variables between groups. There were several significant differences between the flute players and non-musician controls. As illustrated in table 10, the relationship was stronger between the HINT four talker composite and left/right HF DPOAEs for controls compared to flute players on both ears (left $p = 0.04$, right $p = 0.04$). The relationship between working memory and left HF DPOAEs was also significantly different between groups ($p = 0.01$). Combined, these findings indicate that increased cochlear function could negatively affect performance on the HINT 4T. Therefore, there may be other auditory and/or cognitive factors that influence performance on the HINT 4T that were not measured in the present study.

SIN Ability and DPOAEs

Recall that KKS is defined a condition in which the individual has normal audiograms and complains of difficulty hearing speech in noise. Poor outer hair cell function is a suggested etiology for KKS (Zhao & Stephens, 2006). In order for the cochlear etiology of KKS to hold true for this study, individuals must have SIN deficits, normal audiograms, and decreasing DPOAE response amplitudes with negative correlation values: the poorer the outer hair cell function, the higher (worse) SNR thresholds. The relationships between DPOAEs and SIN test results are presented in table 9. The flute player group was found to have no significant relationships between outer hair cell function and any of the speech in noise tests or conditions in the study protocol. Non-musician controls demonstrated a strong relationship between the HINT four talker babble NF and left and right DPOAEs (left $r = 0.70$, $p < 0.05$; right $r = 0.82$, $p < 0.01$), as well as HINT four talker babble composite scores (left $r = 0.75$, $p < 0.05$; right $r = 0.84$, $p < 0.01$). Figures 8, 9, and 10 illustrate these relationships graphically. Performances on the HINT four talker NF by the controls were significantly related to high frequency DPOAEs and with a positive correlation value (left $r = 0.70$, right $r = 0.82$). These data suggest a positive relationship between outer hair cell function and higher (worse) HINT thresholds. As response amplitudes increase in value, HINT thresholds in the NF condition increase, indicating that the difference between the signal and the noise must increase for the listener to be successful recognizing the sentences.

This finding is contrary to the Zhao and Stephens (2006) indication that those with normal audiograms and SIN deficits may have a cochlear etiology. The results would need to indicate lower DPOAE response amplitudes for those with higher HINT thresholds in order for a cochlear etiology to contribute to SIN deficits. The notion that musicians may experience outer hair cell damage causing SIN deficits did not manifest in the present study with the group of flute players that was studied, and DPOAE response amplitudes for flute players were actually higher than those of controls. The data in the present study suggest that something else may be causing the perception of difficulty with SIN, something yet unknown.

Years of Training, Working Memory, and DPOAEs for Flute Players

Flute players in the study demonstrated a lack of significance in the relationship on the total working memory score and years of training ($r = 0.51$, $p = 0.09$), which was derived by combining performance on the two subtests. The Parbery-Clark et al. (2009) study reported a positive relationship which was significant ($r = 0.614$, $p < 0.001$) between working memory and years of training. To determine if any other relationship between working memory and years of training could be found with the present study, the comparison between subtests which comprise the total working memory score were broken out to compare singular aspects of working memory to years of training. A significant relationship was found between years of training and performance on the Numbers Reversed subtest from the WJ III COG, ($r = 0.58$, $p = 0.05$). This subtest requires the individual to reverse then re-state the stimuli after being given a list of numbers. It tests the recall limit of working memory and contains one category, preventing the individual to “chunk” the information into meaningful groups. The Parbery-Clark et al. (2009) study found a significant positive relationship between years of practice and working memory performance when combining the two subtests ($r = 0.614$, $p < 0.001$). It is possible that with a larger number of participants in the flute player group and more participants between 12 and 20 years of experience, the significance of the association in the overall working memory score would become more apparent.

The right ear is the concern for flute players: the instrument is played with the hands directionally on the right side. The author's own experience suggests that sound that is produced usually is perceived at a higher level on the right side, which is consistent with the binaural measurements by Schmidt et al. (2011): sound exposure levels were 95.4 dBA at the left ear, and 97.6 dBA at the right ear, a binaural difference of 2.2 dB. In the present study, left and right mean high frequency DPOAEs were not significantly different for the flute player group (3.95 and 3.90, $p = 0.26$). Researchers have found that exposure to high levels of sound may damage outer hair cell function (Bright & Kastner-Wells, 1994). However, in the present study, outer hair cell function was not significantly different when comparing right and left DPOAEs at high frequencies. It is possible that a more discrete measurement of high frequency DPOAEs, such as 6 to 9 kHz may reveal more information about outer hair cell function than the broad range of high frequencies selected for the present analysis of 2 to 9 kHz.

The Perception of SIN deficits

Participants were asked if they had difficulty hearing speech in noisy environments and gave either yes or no answers. Responses revealed 2/10 participants in the control group and 9/12 in the flute player group answered "yes" to this question. Interestingly, those who claimed to have difficulty from the control group had the highest left ear response amplitudes (mean response level 0.50). In the flute player group, the data tell a different story. The flute player with the lowest levels of responses on the left side answered "no" to this question, as did two others with lower response amplitudes than the rest of the group (mean response level 0.53).

Individual participants' DPOAEs and response on the survey question were previously reported in table 7. The data are organized in terms of least to greatest response amplitudes for the left ear and paired with the right cochlear response amplitudes. Mean response amplitudes and answer to this question are presented in table 8. Moore et al. (2014) found that participants perceived worse hearing ability than is measured with pure tone averages and speech recognition thresholds. It is possible that individuals perceive handicaps in hearing which are not measured via pure tone averages and speech recognition thresholds. The data gained from the questionnaires in the present study may provide some information regarding specific aspects of speech in noise difficulties not yet explored.

Flute players reported difficulty hearing speech in the presence of noise despite of normal pure tone thresholds between the clinically accepted norms between -10 and 25 dB HL. They had normal audiograms, but reported speech in noise difficulties. Many of these flute players could be considered to have KKS, which is a condition in which individuals have normal audiograms but complain of difficulty recognize speech in noise. It is yet to be determined if the flute players' performance on these tests falls outside the accepted norms for the HINT and QuickSIN.

In Vermiglio (2014), the clinical entity of a speech recognition in noise deficit must represent a functional impairment for the individual. He raises several questions for the clinician to answer when evaluating and diagnosing (Central) Auditory Processing Disorders, including the following:

- Which hearing-critical tasks is the patient using in daily life?
- Is the patient limited such that intervention is required?
- Is there a measurable speech recognition in noise deficit?

The test chosen to assess SIN ability is intended to capture the level of impairment. If perceived speech in noise deficits are not measurable using the QuickSIN, is it possible that another test would indicate a clinically significant SIN deficit? The QuickSIN draws upon working memory, an essential cognitive component to interface between long-term memory and information processing. The HINT appears to draw less significantly on working memory skills, reducing the cognitive demand for inhibition of irrelevant noise during the information processing interval. Working memory is significantly related to performance on the QuickSIN (Parbery-Clark et al., 2009). Wilson et al. (2007) propose that the QuickSIN should be used if the examiner desires to use sentence material without the presence of substantial hearing loss, and the standard (steady state) HINT materials are easier and should be used with individuals with substantial hearing loss. Another sentence-based SIN test should be explored to determine its connection with perceived SIN deficits and measurable, clinically significant, SIN deficits by objective assessments. Data should analyzed in a future study to determine the relevance of the HINT using four talker babble in measuring actual SIN deficits when the listener perceives a functional impairment.

Working Memory

Working memory performance was not significantly different between groups (p = 0.44). This suggests that flute players do not have significantly better or worse working memory skills than non-musician controls. The prior study by Parbery-Clark et al. (2009) found significant differences between groups (p = 0.004) with better performance by musicians than non-musician controls on the same working memory measures used in the present study. It is possible that the composition of the musician group in terms of a single instrument (flute) may be a reason why musicians in the present study did not differ from non-musician controls.

Interestingly, no significant relationship was found between working memory and HF DPOAE response amplitudes for the control group. A significant negative correlation between working memory and HF DPOAE response amplitudes for the left ear was found for the flute player group ($r = -0.61$, $p < 0.05$). The relationship between working memory and HF DPOAEs for the flute player group was not significant for the right ear ($r = -0.53$, $p = 0.07$). This implies a trade-off between working memory and outer hair cell function for flute players when considering the left ear: the poorer the outer hair cell function, the stronger the working memory performance. Moore et al. (2014) indicate a connection between age-related cognitive decline and global sensory deterioration for adults age 40-69. The present study included young adults, age 18-30, and provides evidence based on a small group of flute players (n=12) that better outer hair cell function in the left ear may negatively impact working memory capacity.

Working Memory and SIN Ability

Parbery-Clark et al. (2009) found a significant association between working memory and the QuickSIN ($r = -0.578$, $p < 0.001$) as well as the HINT NF ($r = -0.367$, $p = 0.041$), and the correlation was higher between working memory and the QuickSIN. Working memory was purported to be under a higher demand on the QuickSIN than the HINT NF. If working memory was a driving force on the QuickSIN in the Parbery-Clark et al. (2009) for violin and piano players with a significant difference compared to non-musicians ($p = 0.004$), it is possible that something else is contributing to the near-equal performance on the QuickSIN and working measures in the present study for flute players and non-musician controls. Data in the present study need to be analyzed to determine the significance of the relationship between working memory and SIN ability.

Researchers found that working memory was an enhancement for speech in noise ability for musicians (Parbery-Clark et al, 2009). Higher working memory capacity provides the necessary interface to retrieve lexical information and continuously process the signal while ignoring noise. The ELU model and the OPERA hypothesis (Patel, 2011) give insight into why musicians may have better working memory scores than non-musicians in the previous study. Patel (2011) has proposed a comprehensive framework for understanding musician enhancement for the ability to recognize speech in noise at a lower threshold than non-musicians in her paper on the OPERA hypothesis. This hypothesis proposes the following five principles:

O Overlap: Anatomical overlap in the brain networks that process an acoustic feature used in both music and speech (e.g. waveform periodicity, amplitude envelope)

P Precision: Music places higher demands on these shared networks than does speech, in terms of the precision of processing.

E Emotion: Musical activities that engage this network elicit strong positive emotion.

R Repetition: Musical activities that engage this network are frequently repeated.

A Attention: Musical activities that engage this network are associated with focused attention.

Music-driven adaptive plasticity in speech processing networks occurs because five essential conditions are met [overlap, precision, emotion, repetition, attention]. According to the hypothesis, “When these conditions are met, neural plasticity drives the networks in question to function with higher precision than needed for ordinary speech communication. Yet, since speech shares these networks with music, speech processing benefits” (Patel, 2011, p. 2). Musicians, who have experienced auditory perceptual training in a natural context through music lesson, practice, ensemble rehearsals, and performances, have particular enhancement of auditory abilities, which may be reflected in SIN test results.

One possible reason that performance on the HINT SS NF is less strongly related with working memory than the QuickSIN and working memory is the protocol for administering the tests. During administration of the QuickSIN, the participant responds in the presence of the continuous four talker babble. The challenge of constant babble forces the inhibitory mechanisms to actively discriminate the new signal while attempting to finish processing the stimulus. Tompkins et al. (1994) found that in only the most resource-demanding conditions is there an association between working memory capacity and discourse comprehension. The authors found that even those individuals with high working memory capacities exhibited at least a degree of error-prone performances in the most demanding auditory conditions. The HINT protocol presents the stimulus, then is silent while the participant responds. Therefore, the silent processing interval reduces the load required for information processing. In order to compare these two testing protocols to determine if the test stimuli themselves place higher demands on working memory, future research should answer the question of whether the test protocol places higher or lower demands on cognitive capacity by the inclusion of a silent interval on the QuickSIN or the continuation of babble on the HINT 4T.

LIMITATIONS AND AREAS FOR FUTURE RESEARCH

The present study has some obvious limitations. The first limitation is the relatively small sample size of 10 participants in the control group and 12 participants in the flute player group. The small number of participants limits statistical metrics that may be performed. Additionally, a study with low statistical power "reduces the likelihood that a statistically significant result reflects a true effect" (Button et al., 2013). In this respect, significant results in the present study should be taken with caution and not generalized to larger groups of flute players. The author was unable to recruit age-matched controls for the flute players, limiting the ability to use paired t-tests. It is possible that age-matching would provide a better metric with greater statistical power to compare flute players to noon-musician controls.

There are several questions that have arisen which could not be answered with the present analysis of data, and with the study design. The different test protocols for the QuickSIN and HINT 4T provide a limitation in determining which test may be a purer measure of speech in noise ability as previously described. Future iterations of this study design may examine if the babbling during the response period affects SIN performance. Lexical knowledge is a critical component of working memory and RAMBPHO, however, lexical knowledge was not examined as part of the present study protocol. A language test which examines predictability of sentences as well as a lexical knowledge assessment may provide a better comparison for the appropriate application of various SIN tests for individuals with normal hearing sensitivity.

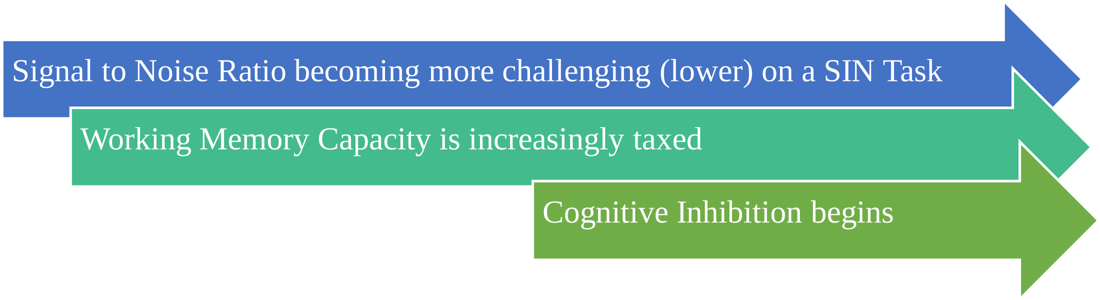
Cognitive performance was measured in the present study using working memory measures. Are there other cognitive processes that were not measured which could examine the impact of better cognition on speech in noise ability? In order to isolate the complexity of these cognitive processes and the impact on SIN ability, future research needs to examine single aspects of attention, memory, and executive functioning with extensive cognitive assessments. Mather and Woodcock (2001) showed a model where the analysis and synthesis of stimuli depends on auditory thinking, stores of acquired knowledge, executive control, and conscious awareness. Auditory thinking is said to be a factor which restricts new learning, which is further affected by either facilitators or inhibitors such as organic issues (hearing, vision, health, medications), situational issues (home, school, work), and executive control (attention, motivation, temperament, and emotional state). Executive control is the foundational skill required to process speech stimuli. Information processing occurs, in which the listener accepts the speech stimuli, manipulates it, and states the target according to the instructions for the task.

As the signal to noise ratio becomes more negative, the SIN task becomes more difficult. Gilbertson and Lutfi (2014) suggest that working memory plays the critical role in easy tasks, and inhibitory controls has a critical role in difficult tasks. As listening difficulty increases, cognitive inhibition may play a more important role in SIN than working memory. A graphic of this phenomenon is depicted in figure 11. The relationship between working memory and performance on the QuickSIN may decrease as the task becomes more difficult.

One measurement of cognitive inhibition is the Stroop color word test (Stroop, 1929). This assessment provides cards of color words that are written in different colors than the word, e.g. **red**, **green**, **purple**, **blue**, and **black**. The participant is asked to read the word rather than state the color of the word. The Stroop test is considered the "gold standard" of attentional measures (MacLeod, 1992). Since attention has been established as an underlying skill essential for working memory (Baddeley, 2003), and the Stroop color word test provides a measure of attention and inhibition, it is possible that a stronger connection may be found between an inhibition task and SIN ability than working memory. In individuals with normal audiograms, and normal working memory capacities, the measurement of cognitive inhibition may provide a way to measure finer cognitive skills than working memory alone (Kemper & McDowd, 2008).

Figure 11

Working Memory Capacity vs. Cognitive Inhibition



Note: Working memory capacity becomes full as the speech in noise task becomes more difficult and the task is considered to be easy. Cognitive inhibition begins when the task becomes more difficult.

The richness of the data set allows for many other comparisons, which may be explored in future research. These comparisons and associations provide hard data to realize potential functional limitations for speech recognition in noise, outer hair cell function, and working memory for flute players as well as non-musician controls. The question arises: does the type of noise make a difference? Can the listener use lexical knowledge to perceive speech-in-noise even if phonemes are not glimpsed? Does lexical knowledge depend on cognitive processes such as attention, memory, and executive functioning? These questions are beyond the scope of the present study, and will take significantly more investigation and isolation of cognitive processes, lexical processes, and variation in background noise. As previously mentioned, the relationship between SIN and working memory in the present study need to be analyzed to determine if results are consistent with the study by Parbery-Clark et al. (2009). Additionally, using a protocol of the QuickSIN which utilizes silence, or a version of the HINT that continues the babble during the response interval may also provide a better comparison of these two sentence-based SIN assessments.

Anderson and Kraus (2010) suggest that "the fact that musical experience enhances the ability to hear speech in challenging listening environments suggests that musical training may serve to enhance education in other domains, such as reading, and may providing an appropriate remediation strategy for individuals with impaired auditory processing" (p. 581). Future research studies focusing on specific instrument groups may include speech in noise tests, working memory and cognitive inhibition tests, and language tests to assess reading abilities.

Chandrasekaran and Kraus (2010) argue for the positive benefits of musical training "As a global intervention strategy in individuals with noise-exclusion deficits" (p. 297). Considering the notion that temporal processing and SIN abilities were shown to be enhanced for musicians compared to non-musicians, this suggests that individuals who are musically trained, despite the potential risk for exposure to high levels of sound, may be appropriate candidates for musical training as an augmentative therapy to improve their ability to exclude irrelevant noise from the signal they are attempting to recognize. Strait and Kraus (2011) suggest that task-specific training improves attention, increasing the “neural capacity to filter out competing irrelevant input.” Inhibition of irrelevant input in the signal leaves room to consider remediation for students struggling with speech in noise. Without a measure of cognitive inhibition capabilities, the effect of cognitive training for enhancing the ability to recognize speech in a noisy environment does not have a valid measurement to contribute to the patient’s plan of care.

CONCLUSION

Three major conclusions can be drawn from the present study:

1) Non-musician controls performed significantly better than flute players on the HINT 4T NF, NR, and Composite Scores
2) Non-musician controls demonstrated a significant positive relationship between HINT 4T NF and bilateral HF DPOAE response amplitudes
3) Flute players demonstrated a significant negative correlation between working memory and left HF DPOAE response amplitudes.

These results differ with the present research comparing musicians to non-musician controls (Parbery-Clark et al., 2009). The present study did not demonstrate a significant relationship between cochlear dysfunction and SIN deficits as previous research has found (Zhao & Stephens, 2006). Future research examining cognitive processing abilities and speech recognition in noise should include a measure of cognitive inhibition and attention, such as the Stroop test (Stroop, 1935). Such a measure may provide better information regarding the impact of cognitive abilities on SIN test performance for individuals with normal audiograms and complaints of difficulty recognizing speech in noise. This study may be expanded in the future to include more participants in both groups with the goal of increasing statistical power; therefore, results should be taken cautiously and efforts should be made to avoid generalizing to the entire flute player population.

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APPENDIX A: IRB APPROVAL LETTER

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
4N-70 Brody Medical Sciences Building· Mail Stop 682
600 Moye Boulevard · Greenville, NC 27834
Office **252-744-2914** · Fax **252-744-2284** · www.ecu.edu/irb

Notification of Initial Approval: Expedited

From: Social/Behavioral IRB
To: Kelly Caldwell
CC: Andrew Vermiglio
Date: 9/24/2014
Re: UMCIRB 14-001138 Speech in Noise for Trained Flute Players

I am pleased to inform you that your Expedited Application was approved. Approval of the study and any consent form(s) is for the period of 9/23/2014 to 9/22/2015. The research study is eligible for review under expedited category #4, 7. The Chairperson (or designee) deemed this study no more than minimal risk.

Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The Investigator must adhere to all reporting requirements for this study.

Approved consent documents with the IRB approval date stamped on the document should be used to consent participants (consent documents with the IRB approval date stamp are found under the Documents tab in the study workspace).

The approval includes the following items:

Name	Description
ASHA.1977.Manual_Pure-Tone_Threshold_Audiometry_Guidelines.pdf	Standardized/Non-Standardized Instruments/Measures
CALDWELL.Consent Signature Form.doc	Consent Forms
Caldwell.Proposal.FINAL.docx	Study Protocol or Grant Application
DPOAEs.pdf	Standardized/Non-Standardized Instruments/Measures
Flute Study Flyer.pptx	Recruitment Documents/Scripts
Killion_et_al.2004.QuickSIN.pdf	Standardized/Non-Standardized Instruments/Measures
Nilsson_et_al.1994.Development_of_HINT.pdf	Standardized/Non-Standardized Instruments/Measures
Participant Questionnaire.docx	Surveys and Questionnaires
Wiley.1987.Acoustic_Immitance_Measures.pdf	Standardized/Non-Standardized Instruments/Measures

The Chairperson (or designee) does not have a potential for conflict of interest on this study.

APPENDIX B

East Carolina University

Informed Consent to Participate in Research

Information to consider before taking part in research that has no more than minimal risk.

Title of Research Study: Speech in Noise, Working Memory, and Outer Hair Cell Function for Trained Flute Players
Principal Investigator: Kelly Caldwell
Thesis Supervisor: Andrew Vermiglio, AuD, CCC-A, FAAA
Institution/Department or Division: Department of Communication Sciences and Disorders
Address: 3310 Health Sciences Building, Mail Stop 668, East Carolina University, Greenville, NC 27834
Telephone #: (252) 375-7584
Study Sponsor/Funding Source: N/A

Researchers at East Carolina University (ECU) study problems in society, health problems, environmental problems, behavior problems and the human condition. Our goal is to try to find ways to improve the lives of you and others. To do this, we need the help of volunteers who are willing to take part in research.

Why is this research being done?
The purpose of this research is to determine the relationships between measures of the auditory system for both flute players and non-musicians. The decision to take part in this research is yours to make. By doing this research, we hope to study the effects of noise exposure on the auditory system of flute players and non-musicians.

Why am I being invited to take part in this research?
You are being invited to take part in this research because you are either a flute player or a non-musician. If you volunteer to take part in this research, you will be one of about 50 people to do so.

Are there reasons I should not take part in this research?
You understand that you should not volunteer for this study if you are outside the age range of 18 to 30.

What other choices do I have if I do not take part in this research?
You can choose not to participate at any time.

Where is the research going to take place and how long will it last?
The research procedures will be conducted at the ECU Health Sciences Building, Department of Communication Sciences and Disorders, Speech Perception Lab. You will need to come to the Health Sciences Building, Room 2310-H. The total amount of time you will be asked to volunteer for this study is one session for approximately 90 minutes.

What will I be asked to do?
You are being asked to provide responses to survey questions, undergo an audiological evaluation, and listen to test sounds. Sometimes you will respond to test sounds, and sometimes you will not. The survey questions are focused on your hearing health and exposure to noise.

What possible harms or discomforts might I experience if I take part in the research?
It has been determined that the risks associated with this research are no more than what you would experience in everyday life. The risk to the participant is negligible and includes possible minor discomfort from sitting and wearing headphones. The test protocol is designed so that no sounds will be uncomfortable. If any sounds are uncomfortable, please inform the researcher immediately.

What are the possible benefits I may experience from taking part in this research?
We do not know if you will get any benefits by taking part in this study. This research might help us learn more about the hearing abilities of flute players, the use of hearing protection, and functional communication. Other people who have participated in this type of research have experienced possible benefits of having a free hearing evaluation. By participating in this research study, you may also experience these benefits. You will receive a copy, and an explanation, of some of the clinical test results. Many participants will keep these results for their records in managing a hearing conservation program.

Will I be paid for taking part in this research?
There is no monetary compensation for your time as a volunteer in this study. You will be provided with a document showing your pure tone and HINT thresholds, and information about hearing conservation.

What will it cost me to take part in this research?
It will not cost you any money to be part of the research.

Who will know that I took part in this research and learn personal information about me?
To do this research, ECU and the people and organizations listed below may know that you took part in this research and may see information about you that is normally kept private. With your permission, these people may use your private information to do this research:

- The University & Medical Center Institutional Review Board (UMCIRB) and its staff, who have responsibility for overseeing your welfare during this research, and other ECU staff who oversee this research.
- Staff members in the Speech Perception Laboratory, Department of Communication Sciences and Disorders at East Carolina University.

How will you keep the information you collect about me secure? How long will you keep it?
Records of data from each experimental task will be kept on a pirate drive secured by ECU ITCS for three years after completion of the research. Data manipulation will occur on computers located in the Health Sciences building 2310-H. Hard copies of data will be kept in a secured file cabinet in the Health Sciences building 2310-H. None of your personal information will be shared during public presentations and/or journal articles arising from this research.

What if I decide I do not want to continue in this research?
If you decide that you no longer want to be a participant in this research after it has already started, you may stop at any time. You will not be penalized or criticized for stopping. You will not lose any benefits that you should normally receive.

Who should I contact if I have questions?
The people conducting this study will be available to answer any questions concerning this research, now or in the future. You may contact the Principal Investigator, Kelly Caldwell, at (252) 375-7584, between the hours of 10am-5pm, or the thesis advisor, Dr. Andrew Vermiglio, at vermiglioa@ecu.edu, or (252) 744-6083 at any time.

If you have questions about your rights as someone taking part in research, you may call the Office for Human Research Integrity (OHRI) at phone number 252-744-2914 (days, 8:00 am-5:00 pm). If you would like to report a complaint or concern about this research study, you may call the Director of the OHRI, at 252-744-1971.

I have decided I want to take part in this research. What should I do now?
The person obtaining informed consent will ask you to read the following and if you agree, you should sign this form:

- I have read (or had read to me) all of the above information.
- I have had an opportunity to ask questions about things in this research I did not understand and have received satisfactory answers.
- I know that I can stop taking part in this study at any time.
- By signing this informed consent form, I am not giving up any of my rights.
- I have been given a copy of this consent document, and it is mine to keep.

____

Participant's Name (PRINT)	**Signature**	**Date**

Person Obtaining Informed Consent: I have conducted the initial informed consent process. I have orally reviewed the contents of the consent document with the person who has signed above, and answered all of the person’s questions about the research.

____

Person Obtaining Consent (PRINT)	**Signature**	**Date**

APPENDIX C

PARTICIPANT QUESTIONNAIRE

1. Do you have trouble hearing? ☐ Yes ☐ No
2. Have you ever worn a hearing aid? ☐ Yes ☐ No
3. Which situations cause the greatest difficulty in hearing?
   ☐ TV ☐ Telephone ☐ Home ☐ Work ☐ Soft Voices ☐ Parties ☐ Large Groups ☐ Lectures
   ☐ Other: ____
4. Do you have difficulty hearing speech in a noisy environment, such as a crowded restaurant? ☐ Yes ☐ No
4. Which ear do you customarily use on the telephone? ☐ Left ☐ Right
5. Have you ever been routinely exposed to loud noises in everyday life? ☐ Yes, years ___ ☐ No
6. Have you ever been routinely exposed to loud noises during recreation? ☐ Yes, years ___ ☐ No
7. Do you have any family members with hearing problems? ☐ Yes ☐ No
8. Do you have any family members with hearing aids? ☐ Yes ☐ No
9. Do you ever get dizzy? ☐ Yes ☐ No
10. Do you ever hear ringing or other noises in your ears? ☐ Yes ☐ No
11. Do you have heart problems? ☐ Yes ☐ No
12. Have you ever been treated for cancer? ☐ Yes ☐ No
13. Have you ever been treated for diabetes? ☐ Yes ☐ No
14. Did you ever get knocked out? ☐ Yes ☐ No
15. What medications do you take regularly?
    ____
16. Do you have any allergies? ☐ Yes ☐ No
17. Do you or have you ever played a musical instrument? ☐ Yes ☐ No
    Primary instrument: ______________________ Start Age: _______ Stop Age: _______
    Other Instrument(s) - include start & stop age:
    ____
18. How many hours per week do you practice and/or perform (on average)? ____________________
19. How many practice sessions do you have each week (on average)? _________________
20. Rate your use of hearing protection during practice sessions:
    (none) 1 2 3 4 5 (always)
21. Rate your use of hearing protection during performances:
    (none) 1 2 3 4 5 (always)
22. Rate your use of hearing protection around loud noises:
    (none) 1 2 3 4 5 (always)
23. What is your first language? ___________________________

APPENDIX D

TEST PRESENTATION ORDER FORM & RANDOMIZATION GUIDE

PARTICIPANT # ____________

Researcher Running Protocol (initials) _______ Date __________

TASK		**ORDER**	**COMPLETED**	**Notes (if needed)**
Consent & Questionnaire		1		
Otoscopy		2		
Tympanometry		3		
Acoustic Reflex Thresholds		4		
DPOAEs		5		
Pure Tone Thresholds		6		
WJ III COG Numbers Reversed		7		
WJ III COG Auditory Working Memory		8		
				LIST NUMBER
HINT – *Practice*		a		List _____
HINT – Quiet		b		List _____
HINT – 4 Talker – Noise FRONT				List _____
HINT – 4 Talker – Noise RIGHT				List _____
HINT – 4 Talker – Noise LEFT				List _____
HINT – Steady State – Noise FRONT				List _____
HINT – Steady State – Noise RIGHT				List _____
HINT – Steady State – Noise LEFT				List _____
				LIST NUMBER
QuickSIN – *Practice*		a		A B C (circle)
QuickSIN 4-talker babble		b		List _____ Track ___
QuickSIN 4-talker babble		c		List _____ Track ___
QuickSIN 4-talker babble		d		List _____ Track ___
QuickSIN 4-talker babble		e		List _____ Track ___

RANDOMIZATION GUIDE

The first 8 items in the experimental protocol should be completed before the HINT and QuickSIN tests. Cross out each randomization as it is used.

1. Use Randomization Guide **A** for choosing whether to do the HINT or QuickSIN first.
2. Use Randomization Guide **B** for choosing 4-talker or steady-state noise on the HINT.
3. When the HINT is the first test, conduct the practice and Quiet conditions first before the noise conditions.
    a. Use Randomization Guide **C** for choosing the order of the noise directions (2 sets needed for each participant).
    b. Write down the lists to be used on the HINT on the test presentation order form, using Randomization Guide **D**.
4. When the QuickSIN is the first test, conduct the practice (circle A, B, or C), then use the order listed in Randomization Guide **E** for the lists to use for the participants.

A. Randomization Guide for HINT (1) or QuickSIN (2)

Set 1	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**	**Set 7**	**Set 8**	**Set 9**	**Set 10**
1	1	2	2	1	2	2	1	2	2
2	2	1	1	2	1	1	2	1	1

Set 11	**Set 12**	**Set 13**	**Set 14**	**Set 15**	**Set 16**	**Set 17**	**Set 18**	**Set 19**	**Set 20**
1	2	2	2	2	2	2	1	1	2
2	1	1	1	1	1	1	2	2	1

Set 21	**Set 22**	**Set 23**	**Set 24**	**Set 25**	**Set 26**	**Set 27**	**Set 28**	**Set 29**	**Set 30**
2	2	2	1	1	1	2	2	1	1
1	1	1	2	2	2	1	1	2	2

Set 31	**Set 32**	**Set 33**	**Set 34**	**Set 35**	**Set 36**	**Set 37**	**Set 38**	**Set 39**	**Set 40**
1	1	2	2	1	2	2	2	2	2
2	2	1	1	2	1	1	1	1	1

Set 41	**Set 42**	**Set 43**	**Set 44**	**Set 45**	**Set 46**	**Set 47**	**Set 48**	**Set 49**	**Set 50**
2	2	1	1	2	1	2	1	2	2
1	1	2	2	1	2	1	2	1	1

B. Randomization Guide for HINT Masking Noise (4-talker or steady-state)

Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10
1	1	2	2	1	2	2	1	2	2
2	2	1	1	2	1	1	2	1	1

Set 11	Set 12	Set 13	Set 14	Set 15	Set 16	Set 17	Set 18	Set 19	Set 20
1	2	2	2	2	2	2	1	1	2
2	1	1	1	1	1	1	2	2	1

Set 21	Set 22	Set 23	Set 24	Set 25	Set 26	Set 27	Set 28	Set 29	Set 30
2	2	2	1	1	1	2	2	1	1
1	1	1	2	2	2	1	1	2	2

Set 31	Set 32	Set 33	Set 34	Set 35	Set 36	Set 37	Set 38	Set 39	Set 40
1	1	2	2	1	2	2	2	2	2
2	2	1	1	2	1	1	1	1	1

Set 41	Set 42	Set 43	Set 44	Set 45	Set 46	Set 47	Set 48	Set 49	Set 50
2	2	1	1	2	1	2	1	2	2
1	1	2	2	1	2	1	2	1	1

C. Randomization Guide for HINT NF (1) NR (2) and NL (3) Presentation

Set 1	Set 2	Set 3	Set 4	Set 5	Set 6	Set 7	Set 8	Set 9	Set 10
NL	NL	NF	NF	NL	NR	NF	NF	NR	NL
NF	NR	NR	NR	NR	NF	NL	NR	NL	NF
NR	NF	NL	NL	NF	NL	NR	NL	NF	NR

Set 11	Set 12	Set 13	Set 14	Set 15	Set 16	Set 17	Set 18	Set 19	Set 20
NF	NR	NF	NL	NL	NR	NR	NR	NR	NR
NR	NL	NR	NF	NR	NF	NL	NL	NF	NL
NL	NF	NL	NR	NF	NL	NF	NF	NL	NF

Set 21	Set 22	Set 23	Set 24	Set 25	Set 26	Set 27	Set 28	Set 29	Set 30
NL	NL	NL	NR	NF	NF	NF	NF	NL	NL
NR	NR	NF	NF	NL	NR	NR	NR	NR	NF
NF	NF	NR	NL	NR	NL	NL	NL	NF	NR

Set 31	Set 32	Set 33	Set 34	Set 35	Set 36	Set 37	Set 38	Set 39	Set 40
NF	NF	NR	NF	NR	NL	NR	NL	NR	NR
NL	NR	NL	NL	NF	NR	NL	NR	NL	NF
NR	NL	NF	NR	NL	NF	NF	NF	NF	NL

Set 41	**Set 42**	**Set 43**	**Set 44**	**Set 45**	**Set 46**	**Set 47**	**Set 48**	**Set 49**	**Set 50**
NR	NF	NL	NL	NR	NL	NF	NL	NR	NL
NF	NL	NF	NF	NF	NF	NL	NR	NL	NF
NL	NR	NR	NR	NL	NR	NR	NF	NF	NR

Set 51	**Set 52**	**Set 53**	**Set 54**	**Set 55**	**Set 56**	**Set 57**	**Set 58**	**Set 59**	**Set 60**
NL	NR	NL	NF	NL	NF	NL	NR	NR	NR
NR	NL	NF	NR	NR	NL	NF	NF	NF	NF
NF	NF	NR	NL	NF	NR	NR	NL	NL	NL

Set 61	**Set 62**	**Set 63**	**Set 64**	**Set 65**	**Set 66**	**Set 67**	**Set 68**	**Set 69**	**Set 70**
NR	NL	NR	NR	NR	NR	NR	NF	NR	NL
NL	NR	NF	NF	NL	NF	NL	NL	NF	NR
NF	NF	NL	NL	NF	NL	NF	NR	NL	NF

Set 71	**Set 72**	**Set 73**	**Set 74**	**Set 75**	**Set 76**	**Set 77**	**Set 78**	**Set 79**	**Set 80**
NL	NF	NR	NL	NF	NF	NL	NR	NR	NR
NR	NR	NL	NR	NL	NR	NF	NL	NF	NL
NF	NL	NF	NF	NR	NL	NR	NF	NL	NF

Set 81	**Set 82**	**Set 83**	**Set 84**	**Set 85**	**Set 86**	**Set 87**	**Set 88**	**Set 89**	**Set 90**
NL	NR	NL	NR	NF	NR	NF	NR	NR	NF
NF	NL	NF	NF	NR	NF	NL	NF	NL	NL
NR	NF	NR	NL	NL	NL	NR	NL	NF	NR

Set 91	**Set 92**	**Set 93**	**Set 94**	**Set 95**	**Set 96**	**Set 97**	**Set 98**	**Set 99**	**Set 100**
NF	NL	NL	NR	NR	NR	NF	NR	NR	NR
NL	NF	NF	NL	NL	NF	NL	NF	NL	NF
NR	NR	NR	NF	NF	NL	NR	NL	NF	NL

D. List Randomization for HINT

8 lists needed for each participant – all must be unique (possibility of 12 lists)

Set 1	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**	**Set 7**	**Set 8**	**Set 9**	**Set 10**
4	4	10	5	6	9	3	8	7	10
9	12	8	3	8	5	5	2	9	11
3	6	12	6	3	2	1	4	12	7
1	9	11	2	7	12	7	12	8	6
8	8	3	12	12	8	12	5	11	4
7	10	9	9	2	6	10	9	5	5
12	3	6	11	11	3	4	3	2	1
10	2	2	4	4	4	9	7	3	9

Set 11	**Set 12**	**Set 13**	**Set 14**	**Set 15**	**Set 16**	**Set 17**	**Set 18**	**Set 19**	**Set 20**
2	3	7	3	7	1	2	6	2	10
9	11	2	4	12	6	7	12	5	1
10	8	5	11	1	5	10	4	11	7
11	1	9	9	9	3	12	3	1	2
5	2	1	5	5	9	3	1	7	12
1	5	8	8	6	2	5	9	10	8
8	10	6	7	11	4	6	10	8	9
3	7	4	1	8	8	8	8	9	4

Set 21	**Set 22**	**Set 23**	**Set 24**	**Set 25**	**Set 26**	**Set 27**	**Set 28**	**Set 29**	**Set 30**
10	8	5	5	1	9	11	4	11	6
5	10	9	11	9	6	7	2	10	7
2	11	8	7	7	2	9	8	2	10
12	2	3	1	2	1	3	1	8	3
9	4	10	8	3	3	6	3	1	2
4	7	1	3	11	10	1	9	6	1
11	6	12	2	8	8	8	12	4	11
3	3	4	4	6	7	4	11	7	12

Set 31	**Set 32**	**Set 33**	**Set 34**	**Set 35**	**Set 36**	**Set 37**	**Set 38**	**Set 39**	**Set 40**
4	1	9	5	12	2	12	11	10	11
6	6	3	11	3	9	10	10	5	2
9	9	6	2	1	11	9	9	2	8
3	3	10	8	8	6	5	8	11	1
10	10	7	3	10	5	6	2	1	7
7	7	2	4	7	3	2	1	8	3
5	2	4	6	4	7	7	12	9	5
1	11	5	10	5	10	4	3	4	9

Set 41	**Set 42**	**Set 43**	**Set 44**	**Set 45**	**Set 46**	**Set 47**	**Set 48**	**Set 49**	**Set 50**
3	1	7	2	7	10	7	8	4	4
12	6	1	5	2	11	11	12	7	6
7	12	4	12	12	7	5	6	9	5
6	8	6	9	3	6	9	3	10	12
5	9	10	3	1	8	12	2	8	1
1	3	11	11	9	5	4	1	2	2
11	4	8	10	11	3	3	11	5	10
2	11	3	8	6	12	6	7	12	11

E. List Randomization for QuickSIN

Possibilities include 1, 2, 6, 8, 10, 11. The practice set selection does not matter.

Set 1	**Set 2**	**Set 3**	**Set 4**	**Set 5**	**Set 6**	**Set 7**	**Set 8**	**Set 9**	**Set 10**
10	2	11	8	11	1	6	6	10	11
6	6	6	6	8	6	11	8	6	10
1	11	8	10	6	10	10	2	8	1
11	1	1	11	10	2	1	1	2	6

Set 11	**Set 12**	**Set 13**	**Set 14**	**Set 15**	**Set 16**	**Set 17**	**Set 18**	**Set 19**	**Set 20**
10	6	10	6	6	2	2	11	6	2
8	11	8	8	10	11	1	1	10	10
11	8	1	1	11	1	11	6	1	11
1	1	11	10	8	6	6	10	8	1

Set 21	**Set 22**	**Set 23**	**Set 24**	**Set 25**	**Set 26**	**Set 27**	**Set 28**	**Set 29**	**Set 30**
8	8	11	8	6	10	11	8	1	1
11	10	1	10	8	1	10	6	10	8
2	2	6	2	2	11	1	11	8	2
6	11	2	11	1	2	2	1	6	11

Set 31	**Set 32**	**Set 33**	**Set 34**	**Set 35**	**Set 36**	**Set 37**	**Set 38**	**Set 39**	**Set 40**
8	11	10	11	11	6	11	1	1	2
11	6	8	1	2	8	8	2	10	6
10	2	1	2	1	10	1	11	8	10
6	8	6	6	10	2	6	8	2	8

Set 41	**Set 42**	**Set 43**	**Set 44**	**Set 45**	**Set 46**	**Set 47**	**Set 48**	**Set 49**	**Set 50**
10	10	11	11	2	1	11	2	11	2
2	11	1	6	11	2	8	10	8	8
1	2	6	8	10	11	1	8	10	11
6	6	8	1	8	6	10	11	6	10

APPENDIX E: SPEECH PERCEPTION LAB INSTRUMENTATION AND CALIBRATION

- 3.5V Halogen Operating Otoscope, manufactured by Welch Allen, model # 21700
- StarMed Video Otoscope 150W Fiberoptic Lightsource, model # 99-7900, serial # FA23069; StarMed CCD Color Camera, JedMed Instruments Co., 70-6001 NTSC; Sony Trinitron Color TV, Sony Electronics Inc., model # KV-13M31, serial # 4009965; Sony Color Video Printer – Mavigraph, UP-1200A
- Interacoustics Clinical Audiometer AC40, serial # 160252, software version 1.70, calibrated 2/8/2010
- GSI 33 Grayson/Stadler ME Analyzer, Serial # 43015, calibrated 2/8/2010
- HINT Pro, manufactured by Bio-logics Systems Corp, version 7.2

HINT Instrumentation and Calibration:

- Sound Level Meter (Bruel & Kjaer, type 2609 Measuring Amplifier)
- 6cc Coupler (Bruel & Kjaer, type 4152 Artificial Ear)
- Pressure Microphone (Larson Davis, model # 2575, calibrated 9/7/10)
- Acoustical Calibrator (Bruel & Kjaer, type 4321, serial # 2463651, calibrated 9/8/2010)
- Headphones (Right: Telephonics TDH 39p, serial # C278983, model # 296D000-1; Left: Telephonics TDH 39p, serial # C278778, model # 296D000-1)
- Speaker System (Justice Active AC-691N, Hi-R Speaker System; Juster AC-691N, serial # FFLA811100973, Pro Juster Inc.)

The headphones were calibrated according to the HINT Pro protocol.

The Calibrate Headphones protocol involves presenting the calibration noise and manually entering the output level into the software. Once this calibration is performed, all stimuli (speech, noise, and tones) will be calibrated. There is also a verification feature to check the broadband and tonal stimuli at two output levels.

We calibrated the measuring amplifier to 94 dB SPL at 1k Hz by plugging it into the acoustical calibrator onto which we placed the 6cc Coupler. We then used the measuring amplifier to test the noise floor in both the test booth and the test administration booth. With the doors closed, the noise floor in the test booth is 32.2 dB(A), and 33.5 dB(A) in the test room.

From the **Calibrate Headphones** screen, we selected the **Telephonics-39, -39P** to specify the headphone model, followed by the respective **Calibrate** option. We then followed the software's prompts through a series of steps to complete the automated calibration measurements. First, we place the left earphone on the 6cc coupler, connected the coupler output to the sound level meter input, and connected the sound level meter output to the external input of the HTD; we disabled the A-weighting at this point, as instructed. The same process was repeated with the right headphone. The HINT software then performed the automated calibration measurements, including calculation of impedance. We then measured the sound pressure level by connecting the coupler output to the sound level meter, as instructed, as the software. The sound pressure level, 94 dB SPL, was then entered into the software. To verify the calibration, each headphone was placed on the coupler, which was then connected to the sound level meter; we enabled the A-weighting on the sound level meter, as instructed, before selecting 1k Hz as the level verification test signal, which yielded a corresponding predicted level.

To ensure that the phases and magnitudes of the right and left headphones were matched, we used the HINT system's **Headphone Matching** feature, which delivers a noise through the headphones while recording the output. We placed the right headphone on the coupler and selected **measure right** to deliver the calibration noise; the process was repeated for the left headphone. After both headphones were measured, we selected the **Evaluate** button to display the magnitude and phase difference graphs. The Average Absolute Magnitude Difference was ≤ 2 dB, and therefore rated as "Good." The Average Absolute Phase Difference was ≤ 30°, and also rated as "Good."

Parameters were not changed from the system's following default settings:

Test Condition	Starting Speech Level	Noise Level [dB(A)]	Starting S/N Ratio (dB)	Step Size (first 4 sentences)	Step Size (rest of sentences)
Quiet	20.0			4.0	2.0
Noise Front		65.0	0.0	4.0	2.0
Noise Right		65.0	-5.0	4.0	2.0
Noise Left		65.0	-5.0	4.0	2.0

Noise starts 10.0 seconds before speech.

- Adaptively vary level of speech
- Post a warning if variability is ≥ 95th percentile (if standard step sizes are used)
- Current Test Site: (ECU Speech Perception Lab)
- Current Speech Set: American English, adult
- Using standard headphones

APPENDIX F: PARTICIPANT HANDOUT ON HEARING CONSERVATION

HEARING CONSERVATION

If you are regularly exposed to loud sounds for an extended period of time, you could be at risk for a sensorineural hearing loss. This type of hearing loss may be permanent. Consider using hearing protection in order to decrease your exposure to loud sounds. Flat attenuation ear plugs lower the sound level across all frequencies, and not just the high-frequency sounds. Listening to music with flat attenuation ear plugs generally sounds better than when listening with typical foam ear plugs. The proper use of hearing protection will reduce the risk of noise-induced hearing loss.

Hearing in Noise Test

The Hearing in Noise Test (HINT; Nilsson et al., 1994) is used to assess an individual's ability to recognize speech in quiet and in background noise. The threshold represents the level in dBA for the quiet condition or the signal-to-noise ratio for the noise conditions where the listener can recognize 50% of the sentences. Your HINT thresholds from today's session are listed below. WNL means within normal limits.

HINT in Quiet

dBA	WNL

Table 1. Speech recognition in quiet thresholds.

HINT in Noise

	dB SNR	WNL
NF		
NR		
NL		

Table 2. Speech recognition in noise thresholds

Pure Tone Thresholds

Pure tone thresholds are a measure of your hearing sensitivity to various frequencies. The normal range for pure tone thresholds for adults is -10 to 25 dB HL. A threshold > 25 dB HL represents a hearing loss. You should consider keeping track of your pure tone thresholds in order to monitor changes in your hearing sensitivity.

	250 Hz	500 Hz	1000 Hz	2000 Hz	3000 Hz	4000 Hz	6000 Hz	8000 Hz	WNL
Left (dB HL)									
Right (dB HL)									

Table 3. Air-conduction pure tone thresholds.

Monitor your Hearing

It is advisable for musicians and those working in noisy environments to get an audiological evaluation once per year. The Department of Communication Sciences and Disorders always needs participants for research studies about speech and hearing. If you are interested in being a participant in future research studies pertaining to auditory function, contact Dr. Andrew Vermiglio at (252) 744-6083 or vermiglioa@ecu.edu to see if there is a study for which you may qualify.